

On the economic effects of research and development

– Executive summary

CEA

VI FREMMER VIDEN

“There is nothing a government hates more than being well-informed; for it makes the process of arriving at decisions much more complicated and difficult.”

– John Maynard Keynes

*The report is commissioned by the Ministry of
Higher Education and Science.*

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Introduction

It is important for a government to be well informed when it comes to prioritizing limited resources. For example, what is the best way to subsidize private research and development (R&D)? What is the effect of research-based education? Good decision-making is based on evidence, but it is unusual for policy questions to be informed by a single study. Solving complex real-life issues typically requires a huge volume of published research. This literature review summarizes the most recent high-quality research on the effect of public R&D investment and R&D policies on firm performance to help in decision-making and focus future research policies.

The private sector plays an important role in the discovery and diffusion of new knowledge and technologies. R&D and innovation create a competitive advantage; however, due to the risky and uncertain nature of R&D projects and the public good characteristics of knowledge, firms tend to underinvest in R&D activities (Arrow, 1962; Nelson, 1959), because the private returns to R&D are below the social ones.

Governments therefore seek to correct for this market failure by balancing the public and private returns of R&D via subsidies, public research and other policy measures. These measures may lead to free-riding behavior on the part of the corporate sector; government subsidies may, however, also increase private R&D, if public and private R&D are complementary rather than substitutes. Our review covers the most commonly applied policy measures to promote research and innovative activity: university research and education,

technology transfer, R&D collaboration, tax subsidies, and direct R&D subsidies. We also review the latest literature on the private and social returns of private investment in R&D. Most policy measures have been well analyzed in previous work, which forms the fundament of our present analysis. We complement that work with the most recent studies and, in particular, review papers dealing with Denmark.

Even though the literature on the relationship between R&D policy measures and R&D outcomes is vast, most studies measure correlations rather than causal effects. The existing evidence does generally suggest positive relationships between corporate R&D and the set of policy measures at governments' disposal. Apart from the need for better identification strategies, possibly through field experiments (List and Rasul, 2011), researchers would need to have more comprehensive data on the entire set of national and international policy measures. This would make it possible to analyze the efficacy of individual policy measures and investigate possible additionalities between R&D support programs.

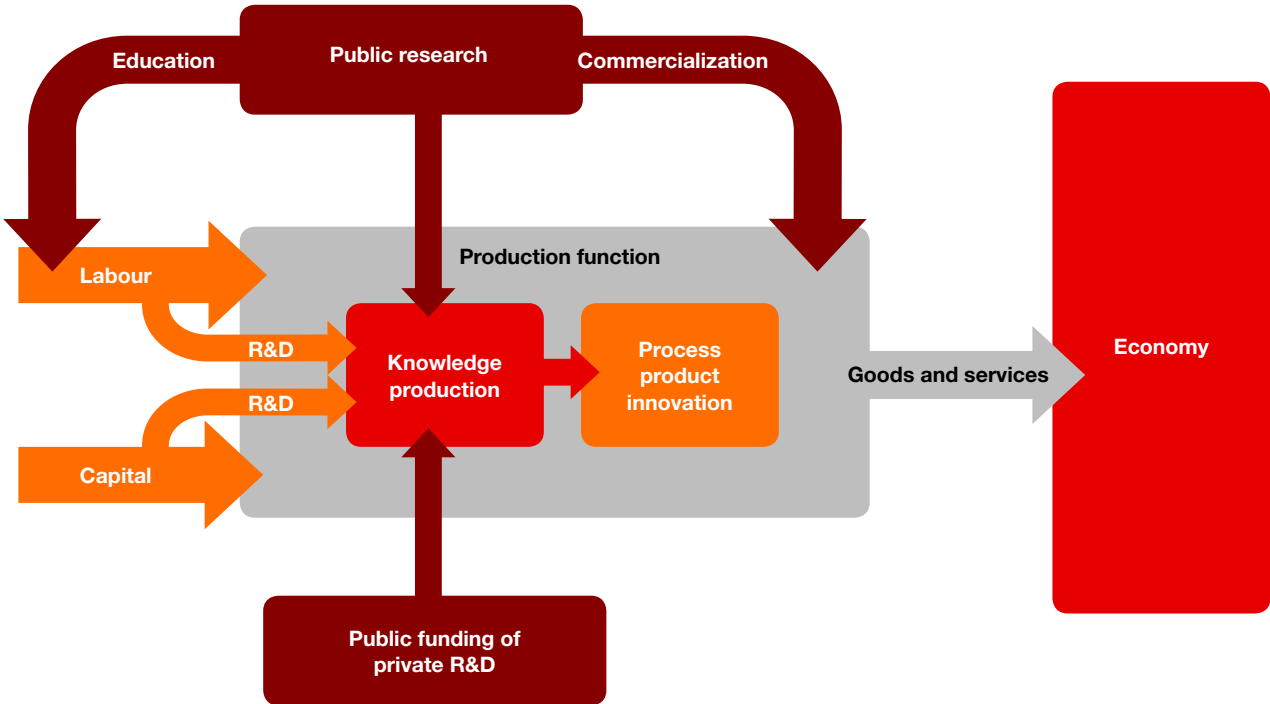
Our review focuses mainly on the short-run economic effect of R&D investment because, in fact, there is not much research on the long-run economic effects of R&D policies. The sparse literature on long-run effects arrives at very large effects, in particular for technology adoption. Due to the complexity of general equilibrium effects that would also take into account changes in competitive advantage (Acemoglu et al., 2013), we focus on partial equilibrium models.

Overview of the review

Our review falls into four core chapters: the effects of private R&D on firm performance and economic growth; public funding of R&D investment; public research education and the R&D labor market; and the effect of knowledge transfers on firms. Figure 1 shows how these four elements relate to one another.

FIGURE 1.

A simple model of R&D investment



The cornerstone of the figure is the knowledge production function of private firms. Chapter three of our review deals with the private incentives to invest in R&D and knowledge spillovers to other firms.

The remaining three chapters deal with the environment outside of the private-sector R&D box and primarily study the role of the public sector. In chapter four, we review the effect of direct public funding for private R&D investment, specifically discussing direct subsidies and tax incentives. In chapter five, we analyze the role of public research as a knowledge supplier and producer of skilled labor. Our sixth chapter is concerned with knowledge transfer between the public and private sector, like commercialization of research or collaboration between public research and private research.

We have covered the most important channels from R&D investment to the market economy in the review. However, there remain a few other channels that we do not cover. First, we have not touched upon innovation that is directly not related to R&D, like organizational and marketing innovations. Research-based education, in particular in the social sciences and humanities, is important for these types of innovation. Second, we do not deal with rent spillovers, which occur when firms purchase products with embodied R&D and where the product price may not fully cover the value of the product. This channel seems to be important in the long run, when new technologies are adopted. Third, public research does not only benefit the economy indirectly through the private sector, e.g., research on health and health-related questions improve the hospitals' treatment of diseases and improve longevity; this could increase the labor supply and improve the economy.

Results

Summary table 1 summarizes the main findings. Most of the investigated policy measures positively affect the economy. It is not possible to present a number or range of numbers due to the substantial heterogeneity between the studies. This also means it is impossible to compare the size of the effect across the different measures. The evidence is strongest for R&D subsidies and R&D taxes, which is due to the larger number of studies with good quality and clear transmission paths, compared to the other policy measures.

We also summarize the results for private and social returns on private R&D investment. We find, in line with other reviews, that the private rate of return is high, reflecting a substantial risk premium. Knowledge spillovers are positive, which means that the social rate of return is higher than the private rate of return.

The evidence in the table is likely to hold for Denmark because we focus mostly on economies that are broadly similar to the Danish. Moreover, studies exist for Denmark on all policy measures with the exception of R&D taxes.

SUMMARY TABLE 1.

Effect of policy measures and R&D investment on the economy and the level of evidence

Note: As no general agreement exists on classifying evidence, summary table 1 is based on the authors own classification. Authors hierarchy of evidence (highest first): Strong, indication, modest

Policy measure	Expected effect	Evidence
R&D subsidies	Positive	Strong
R&D taxes	Positive	Strong
Public research and education	Positive	Indication
Knowledge transfer	Positive	Modest
Private sector	Expected effect	Evidence
Private R&D investment	20%-30% p.a.	Indication
Private R&D knowledge spillovers	Positive	Indication

Evidence can be strong or less strong. For example, if many studies point in the same direction and none or only a few point in different directions, this would indicate an effect. If some of the studies are high quality,¹ we will say that the evidence is strong. If a large number of studies exist and the majority point in one direction, but some studies point in other directions, we will say that the evidence is modest.

As many studies do not focus on employment or productivity, “economy” must be understood broadly. Instead, the studies focus mainly on much narrower measures, like the level of private R&D investment and innovation. Increasing R&D investment and innovation are likely to create positive effects on the economy. Due to the very long time lag between research and research-produced innovations becoming a part of the market, focusing on these earlier effects is the best that can be done.

R&D subsidies and R&D taxes

Generally, studies conducted over the last two decades on the empirical evaluation of direct public R&D support clearly lead to the conclusion that there is substantial empirical evidence that public R&D subsidies stimulate private R&D investment, and some empirical evidence that direct R&D support can enhance innovation outcomes, such as patents, innovative sales, and R&D employment, as well as productivity.

The current understanding in empirical research on the effects of tax credits leads to the conclusion that tax credits can stimulate private R&D investments on a level roughly equivalent to the foregone taxes. Tax credits increase the amount of corporate R&D efforts and lower its marginal costs.

1. High-quality studies have a good research design (i.e., RCT-study or MRA-study) and are executed well.

Both policy instruments are able to stimulate R&D in the private sector. Empirical studies suggest that tax incentive schemes are effective in the short-run and constitute an effective means to increase R&D efforts, particularly in SMEs, low-tech sectors, and countries with incremental incentive schemes. Notably, the tax incentive schemes need to be designed in accordance with the general tax scheme; direct public R&D subsidies require a minimum grant size and time in order to create additionalities. Empirical evidence shows that direct subsidies are especially effective for stimulating innovation in areas with higher degrees of innovation novelty.

From a policy perspective, building on Guellec and Van Pottelsberghe (2003), we would like to draw some general policy recommendations. First, any type of policy instrument is more likely to show the desired effects if the policy is integrated in a long-term policy framework and is somehow stable over time. The positive effects might be related to the decrease in uncertainty for firms, and hence enable better strategic planning and coordination. Second, there should be consistency between the different policy instruments, which requires coordination and management between the agencies involved. Third, positive effects from public funding for R&D in the private sector require a certain amount of governmental support; hence the subsidy should neither not be too low nor too high. Fourth, the policies' instruments and schemes (e.g., awarding criteria, level of grants) should be designed in alignment with the national innovation system and the national or regional industry structure.

Public research and education

The literature on the direct link between public and corporate research is vast and shows that public research institutions have a significant economic impact on industrial research. To study these direct relations, scholars have mostly used patent citations and survey data. These data show that public research crowds in, rather than crowds out, private R&D.

Scholars have recently begun to use register data, coupled with patent and patent citation data as well as surveys, which allows them to track the entire working history of individuals. The corresponding studies show that there is a statistically significant and economically positive link between public research and private sector innovations. Most studies do, however, focus on a few high-technology sectors, while little is known about public research effects on low-tech industries. Existing research has so far ignored the reverse relationships from industry to university (e.g. whether private funding effects public research).

The training of qualified research workers constitutes an important mechanism through which university research affects industry. Studies have shown that these movements constitute an important mechanism through which academic knowledge disseminates. Another mechanism of knowledge transfer is the startup activity of graduates and post-graduates; the evidence on their importance is scant, in contrast to the research literature on direct university spinoffs. Existing research does, however, show that the number of startups founded by (post-) graduates is rising and that these startups do at least as well as other startups.

A key problem with the literature on the effects of universities on industry is that causal effects are inherently hard to identify, as the sorting and matching of workers is non-random, knowledge flows between university and industry may be bi-directional, and international mobility is characterized by self-selection. Quasi-experiments of the type conducted by Christensen et al. (2016) would constitute an important step towards a more proper assessment of university-industry interactions.

Apart from educating labor, a second key purpose of universities is the generation of knowledge, of course often indirectly transmitted through qualified academic labor. There exists a vast body of evidence showing that proximity to universities increases industrial

innovation. This is because universities constitute an important source of information for industrial innovation and universities not only increase innovation, but also enable firms to tap into new technology fields. These studies are empirically often not particularly well identified and solid evidence for Denmark is lacking. The existing evidence does, however, indicate that universities constitute important contributors to industrial innovation not only through education, but through knowledge generation as well. University-based research has a very long tail and may affect industry with a delay of up to 20 years. It hence seems advisable to maintain basic “blue sky” funding to universities to lay the fundament for future industrial innovations by encouraging basic science.

Knowledge transfer

In addition to public support mechanisms, such as subsidies and tax incentives, which are designed to increase input additionalities, such as R&D investments in the private sector, additional policy measures support the commercialization and diffusion of technological knowledge from universities and other research institutes.

To review the effects of knowledge and technology transfer from academia to the private sector, we account for policy instruments, such as: research partnerships; research services, including academic consulting; technology transfer offices; academic entrepreneurship (i.e., academic spin-offs); intellectual property rights; and further entrepreneurship and technology policies. Taking all this together, these public support policies address market failures in R&D and innovation and aim to contribute to increasing innovation in the private sector.

Importantly, our review finds that broadly-accepted empirical evidence on transfer mechanisms is lacking. Hence, we focus on individual studies that address the specific policy measures indicated above.

First, the university-industry partnership constitutes a very commonly practiced policy measure to increase industrial as well as academic innovation. We find that these research partnerships have a positive effect on innovation; however, there is a lot of heterogeneity. In particular, large firms can benefit when opening-up towards science partners for radical and incremental innovations. Small firms have more difficulties in collaborations with science partners (i.e., with respect to incremental innovations). Notably, the effects of research partnerships should retain a lot of attention by policy makers, as it constitutes a very important and frequently used policy measure and receives a lot of public funding.

Second, research services, in the form of academic consulting, constitute a very important means of technology and knowledge transfer for R&D executives in industry. Empirical evidence on academic consulting is, however, missing, with one exception that indicates no significant effect.

Third, there are many studies on technology transfer offices (TTOs) that highlight appropriate TTO configurations, but there is very little robust evidence regarding the outcomes of TTOs.

Fourth, an increasingly popular policy instrument is academic entrepreneurship, in terms of academic spin-offs, science parks, and academic clusters and incubators. Our reviews find that the results on the effects of incubators are mixed, and science parks obviously increase collaboration, particularly industry-science collaboration. With respect to the outcome effects of clusters, there are only a few empirical studies; these studies report an increased likelihood of cluster participants to become innovators due to collaboration. In particular, collaboration with public research institutes is promoted within clusters. In addition, clusters lead to an increased availability of suitable R&D labor. Importantly, the results on clusters show that distance matters: being located in

a cluster has positive effects, and these effects are strongest for biotech firms.

Fifth, there is not much empirical literature on the outcome effects of intellectual property rights. Our review points out that licensing has large effects on GDP, industry output, and employment.

Private and social return on private R&D investment

The literature shows that the private rate of return of R&D is positive, significant, and higher than the rate of return of other types of capital.² Most of the studies find that the annual rate of return is between 20% and 30%; however, the effect ranges from 3% to 66% in the review, and different data, different definitions, etc., drive some of the differences in results.

Most of the available papers apply data on firms in the manufacturing sector; however, increasingly more studies are analyzing the service sector, and the results are comparable in magnitude with the manufacturing sector with respect to the rate of return. Across industries, high-tech sectors have better technological opportunities and invest more in R&D. There is no systematic evidence that some industries have higher returns than others.

A number of papers utilize multi-country datasets to investigate the difference in the rate of return between countries. This type of study is interesting from a policy perspective, because they provide evidence of the importance of innovation systems. The evidence shows that EU countries have lower investment in R&D than in the US, but the EU also has a lower return on R&D investment. This points to a superior US innovation system, compared with the EU.

There is some evidence that investment in R&D has a diminishing rate of return as investment in R&D-intensity increases within the firm; however, there are no signs in our literature review that the rate of return of private

R&D investment drops over time, despite an overall increase in global research intensity.

The results for Denmark are in line with the literature and we find that the annual rate of return is in the range of 20% to 30%. One must be careful in comparing the rate of return with other types of capital; for the return to be as high as 20%-30%, the investment must be productive immediately, and R&D projects sometimes take years to complete and become productive. The remaining difference in the return, compared to other types of investment, may be attributed to the risk premium.

In the literature on the social rate of return of R&D, the estimate is found to be (much) larger, 2- to 3-fold, than the private rate of return of R&D, indicating that the knowledge spillover effect to other firms is potentially large. The most common transmission channels of knowledge are technological and geographical proximity, and both channels seem to be important; one does not appear to be more important than the other. The spillover effect is positive intra-industry, inter-industry, and internationally. In a small open economy, the international channel plays a larger role than the other channels relative to large countries. Business stealing and product market rivalry have negative spillover effects – although not of the same magnitude as knowledge spillover.

The Danish evidence suggests lower knowledge spillover effects. One explanation is that the number of receiving domestic firms is smaller in a small country; however, the competitive advantage created by R&D investment and innovation have a negative effect on other firms, which lose market share. These effects are also more likely to hit foreign firms in small open economies and externalize some of the negative effects of innovation.

² The high return is due to a large risk premium. Comparisons with other types of capital is not easy because, for example, a machine is almost always instantly productive, whereas R&D projects require "time to build."

Other results

The composition of public research activities, i.e., basic versus applied, competitive versus non-competitive, and research fields, was part of our study, which was commissioned by Ministry of Higher Education and Science. We did not find much literature on these subjects, and we are therefore unable to come up with results. Public research activities are such a large share of the public research budget that there is a real need for evaluation. Many public research activities are expected to have long-term impacts and it might be very important, in the long run, for the innovative competitiveness of the economy. In particular, universities are educating labor, which the literature has shown is important for innovation and growth, but we do not know much about how important research activities in universities are for this effect.

Our review also shows that there is a positive relationship between the mobility of labor and corporate innovation, as well as knowledge diffusion. In addition, mobility does not even appear to be a double-edged sword; existing studies show that both patenting and the knowledge absorption of the firm that loses a R&D worker can increase. This implies that policies restricting labor mobility may negatively affect innovative activity and knowledge diffusion. The use of register data and the identification of individual inventors in this dataset, as well as the design of an appropriate empirical identification strategy, would constitute important next steps in our understanding of the mapping between labor mobility and innovation.

Conclusion

The ambition of our literature review was to cover the most commonly applied policy measures to promote research and innovative activity: university research and education, technology transfer, R&D collaboration, tax subsidies, and direct R&D subsidies. Even though the literature is generally based on quite weak empirical identification, it generates a number of consistent findings. This is useful evidence that can guide policymakers on prioritizing limited resources; however, these findings are mainly based on correlations, so causality cannot be claimed. By the same token and given the vast amounts of money spent by governments on R&D all over the world, it seems advisable to allocate some of these funds to policy experiments, as is common practice in e.g. labor economics. Better data simply leads to better results as well as more comprehensive policy advice.

Search strategy

We were asked to conduct a broad systematic search of the most recent reports in the literature. Box 1 documents our search strategy.

BOX 1.

Overview of search strategy

Preselected literature

Initially, the authors and Ministry of Higher Education and Science compiled a list of high quality papers and other writings.

Systematic literature search on ECONLIT

- Seven research questions were formulated that covered the review
- Two-four concepts were developed for each question
- Synonyms for each concept were listed
- Search provided us with 2276 journal articles (2010-2016) and 595 working papers (2013-2016)

Grey literature

- 21 homepages of research repositories, government agencies, think tanks etc. were manually searched

Screening the literature from ECONLIT in three stages. The initial search gave a huge number of papers of little interest to the review. These were screened first by title and then by abstract. Papers with a very narrow industry focus and with a focus on transitional, emerging, or developing economies were screened away. Finally, 204 journal articles and 21 working papers were read and ranked according to methodological rigor, relevance for the review, and importance of findings.

We did not score the grey literature. Since it does not have to meet up to certain scientific standards, they are typically much harder to judge.

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VÆKST GENNEM VIDEN

DEA er en ideologisk uafhængig tænketank, der arbejder for, at Danmark øger sin værdiskabelse og vækst samt tiltrækker internationale virksomheder gennem viden om uddannelse, forskning og innovation.

Tænketanken DEA kæmper grundlæggende for, at flere unge får en uddannelse, der efterspørges; at forskning bliver omsat til innovation i private og offentlige virksomheder, og at Danmark er et attraktivt land for videnbaserede virksomheder.

DEA vil nå sine mål gennem:

- Analyser og undersøgelser, der styrker DEAs dagsorden
- Involvering af virksomheder, uddannelsesinstitutioner og organisationer via partnerskaber og projekter
- Udfordring af vanetænkning og bidrag til løsning af samfundsudfordringer

On the effects of research and development: A literature review

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1. Introduction

The economic return to public and private research and development (R&D) is of enormous interest to academics and policy makers alike, since public spending in growth-enhancing areas seems more important than ever given austerity and slow economic growth in many countries.

The European Union (EU) targeted an overall level of three percent relative to gross domestic product (GDP) in the Barcelona strategy, of which two thirds were supposed to be undertaken by the private sector. Denmark has achieved this ambition already, although a recent drop in private R&D might make it hard to maintain. A major problem with the target is that reaching this level of investment does not guarantee growth. It is also necessary that growth-related innovation projects are the target of the R&D investments.

The private sector plays an important role for the discovery and diffusion of new knowledge and technologies. R&D and innovation creates a competitive advantage. However, due to the risky and uncertain nature of R&D projects as well as the public good characteristics of knowledge, firms tend to under-invest in R&D activities, as seen from a societal perspective (Arrow, 1962; Nelson, 1959). Given this classic public good problem, R&D and innovation are subject to market failure (Martin and Scott, 2000; Romer, 1990), which means that the investments in R&D activities from the private sector are below the socially optimum level.

Governments hence seek to equate the public and private returns to R&D by subsidies and other policy measures. These measures may lead to some degree of “free-ride” behavior on part of the corporate sector. Government subsidies may, however, also increase private R&D if public and private R&D are complements rather than substitutes. Our review covers the most commonly applied policy measures to promote innovative activity: university research and education, technology transfer, R&D collaboration, tax subsidies and direct R&D subsidies. We also review the latest literature on private and social returns to private investment in R&D. Most policy measures have been well analyzed in previous work, which forms the fundament of our present analysis. We complement that work with the most recent studies and in particular review papers dealing with Denmark.

While a lot of ink has been spilled describing the mapping between R&D policy and R&D outcomes, the empirical identification of causal effects is surprisingly weak. However, the existing evidence points towards generally positive relationships between the various policy measures and corporate R&D. To produce firm policy conclusions, one would need to have much more detailed and comprehensive data on all kinds of national and international policy measures as well as field experiments as they are commonly conducted in labor economics (List and Rasul, 2011).

The focus of this review is on the short-run effects of R&D investments, since there is little evidence on long-run effects. The sparse literature on long-term effects suggest that these effects are very large, in particular for technology adoption. Due to the complexity of general equilibrium effects that would also take into account changes in competitive advantage (Acemoglu et al., 2013), we focus on partial equilibrium models.

We focus on research activities that influence growth, and those activities that improve the general knowledge level and wellbeing/quality of life is not included. In the next chapter, we discuss how we organized the literature review. Chapters three to six constitute the central element of our review. Chapter three reviews the existing evidence on rate of return to private investment in R&D. Chapter four is devoted to literature on public funding of private R&D and public research. Chapter five deals with research-based education and the labor market for R&D workers. Chapter six covers knowledge transfer policies. Chapter seven concludes.

2. Methodology

1. Introduction
2. **Methodology**
3. The effects of private R&D on firm performance and economic growth
4. Public funding of R&D investment
5. Public research, education and R&D labor market
6. What is the effect of knowledge transfer on firm performance or growth?
7. Conclusion

Literature

The funding body of our review is the Danish Agency for Science Technology and Innovation (DASTI), and we have applied DASTI's requirements to the coverage of our review.

We divided our review into four main chapters, including effects of private R&D (Ch. 3), public R&D funding (Ch. 4), public research education and the labor market for R&D workers (Ch. 5) and knowledge transfer (Ch. 6). Initially, we compiled a list of high-quality research articles based on the knowledge of the area of the authors and DASTI. This pre-selected list of papers can be seen in Annex A.

We formulated two research questions for chapters three, four and five, while chapter six only covers one research question. An important decision was made to focus mainly on knowledge spillovers of R&D. This excludes an important long-run effect of R&D investment due to technology adoption. Comin (2000) and Comin et al. (2007) make the point that most of the societal return to R&D comes through technology adoption. To shape the search, we developed key concepts from the research questions. For each research question, we developed two to four key concepts, which we could combine in a search with an AND operator; that is, research question one was "What is the effect of private R&D investment on firm performance and growth", which we derived three key concepts: "R&D", "effect" and "firm" (cf. Table 1).

Using research question one as an example, we can demonstrate the process:

- Research question: What is the effect of private R&D investment on firm performance and growth?
- Key concepts: R&D; effect; firm
- Synonyms: Innovation, R&D, research and development; effect, impact, return; firm, industry,

Table 1 displays the organization of our review, the associated research questions and the derived concepts. Additionally, we developed a list of synonyms for each key concept, which we combine with the OR operator in the search; for example, for R&D, we listed synonyms like innovation, research, development, etc. The full lists of search strings are given in Annex B.

TABLE 1.*Research questions and concepts*

Our search was conducted using ECONLIT and resulted in 2276 articles from journals for the period 2010 to 2016 and 595 working papers for the period 2013-2016.

Section	Research questions	Concepts
Chapter three: Effects of private R&D on firm performance and economic growth	<ol style="list-style-type: none"> 1. What is the effect of private R&D investment on firm performance or economic growth? 2. What is the societal return of private R&D investment? 	<ol style="list-style-type: none"> 1. R&D; effect; firm 2. R&D; effect; societal
Chapter four: Effect of public funding of R&D	<ol style="list-style-type: none"> 3. What is the effect of public funding of research on private R&D investment or firm performance? 4. How does the distribution of public funding/research matter for knowledge, private R&D investment or firm performance? 	<ol style="list-style-type: none"> 3. R&D; effect; subsidy 4. R&D; public; fund; distribution
Chapter five: Labor market for R&D personnel and education	<ol style="list-style-type: none"> 5. How important is investment in research based education? 6. How important is the mobility of R&D personnel for investment in R&D and knowledge diffusion? 	<ol style="list-style-type: none"> 5. research based; learning; firm 6. R&D; personnel; mobility; diffusion; firm
Chapter six: Knowledge transfer	<ol style="list-style-type: none"> 7. What is the effect of knowledge transfer on firm performance or growth? 	<ol style="list-style-type: none"> 7. Knowledge ; technology transfer; effect

Table 2 shows how the 2276 articles were distributed by research questions. A similar table is provided for working papers in the Annex C.

TABLE 2.

Search results for articles in journals

Research question	# of hits	#screening on title	#screening on criteria
(1)	1115	460	48
(2)	396	48	36
(3)	229	17	54
(4)	139	31	27
(5)	57	21	24
(6)	37	15	14
(7)	303	84	46
TOTAL AMOUNT	2276	592	204

We screened the literature in three steps. Our screening was first based on the title of the paper and secondly on our reading of abstracts. Two of us sorted the papers in three piles according to whether the paper should continue to the next stage 'yes', not continue to next stage 'no' and maybe continue 'maybe'. We then discussed papers that we did not agree on before making the final decision. This was done for titles and afterwards for abstracts. In the process, we also used ranking of the journal in case of doubt. Columns two and three show the number of papers that went to the next stage. In the final step, we read the articles and

gave them points according to relevance (0-5 points), importance of findings (0-5 points) and methodological rigor (0-5 points).

The total number of articles that entered the screening process was 2276. The initial search produced a huge number of papers that were of little interest for the review. 592 went into the abstract screening process and have been re-distributed to the related research questions. In this stage, we excluded a number of papers: papers on emerging, transitional or developing economies; papers with too narrow an industry focus;

comments and book reviews; and qualitative research that lacked an empirical foundation. Finally, 204 papers were subjected to the criteria screening process, which is based on methodological rigor, relevance for the report and importance of findings for the report. We downloaded all papers and read them. In Annex D, all papers that made it to the last stage are shown. We did not include all papers in the review but only those of high quality. We defined a threshold which the papers should pass to enter the review. The threshold was not the same across research questions because, for example, methodological rigor differed, and we took that into account by lowering the standard in research questions with low scores. In Annex B, the papers that scored above a threshold to enter into the review are listed first. The resulting sample of papers was 101. As we wrote in the report, it was necessary to go back and revise the scoring, so the final literature list does not fully correspond to papers that met the threshold. We did a similar screening on working papers from ECONLIT. However, we were much stricter on relevance, because the working papers had not been peer reviewed, and they do not necessarily live up to the scientific standard of peer reviewed papers – see the list of papers in Annex E.

In addition, we wanted to include grey literature in the search. We compiled, together with DASTI, a list of homepages that were manually searched for relevant literature. Most of this literature included working papers that were not peer reviewed. Again, we were stricter on relevance. The full list of grey literature is in Annex F. We did not score the grey literature like journal articles and working papers in ECONLIT. The reason is that these reports are seldom well documented, which makes it hard to judge their quality.

Despite the broad systematic search, we did not cover certain areas particularly well. First, some topics are not covered at all. For example, we wanted to cover subjects like composition of public research funding, basic versus applied and competitive versus core composition on scientific fields and how important it is for firm performance. These topics turned out to be completely unexplored. Also, the issue of research based education was unexplored. Second, the very strong focus in the search on firm, industry and economy filters away papers with a strong focus on funding of public research and its impact on things other than the private sector. Third, we cover macro effects but in a limited sense. Most of our papers are based on micro data and almost exclusively on partial equilibrium models. In principle, these effects are also the macro effects. At least two important aspects must be taken into account. First, the sample must be representative, which is often not the case. Most studies are based on innovative firms, which is a small (but important) sub-population of the population. Second, partial models ignore general equilibrium effects. The latter include price effects, but competition induced by innovation can also have some very important negative consequences. There is some recent literature that includes these effects (Acemoglu et al. 2013). However, these models, which are highly complex, do not solve the difficult identification of knowledge spillovers and only include heterogeneity – which is found as very important in all micro studies in a limited way – are not part of the review.

3. The effects of private R&D on firm performance and economic growth

1. Introduction
 2. Methodology
 - 3. The effects of private R&D on firm performance and economic growth**
 4. Public funding of R&D investment
 5. Public research, education and R&D labor market
 6. What is the effect of knowledge transfer on firm performance or growth?
 7. Conclusion
- Literature

The private sector is important for discovering new products/processes and making innovation, which it brings to the market. Diffusion of technologies through private markets is central to economic growth. The existence of spillovers is the main argument for public intervention with public research and public funding of private R&D investment, which we discuss more intensively in chapters four, five and six. This chapter will review the results from the econometric approach to estimate private and societal rates of return to private investment in R&D. Moreover, we will base the review on papers that apply the production function approach to recover the rates of return.

Section 3.1 discusses the private rate of return to investment in R&D, and Section 3.2 discusses the societal rate of return to investment in R&D. There is a strong relationship between the societal and private rates of return, because the societal rate of return to R&D investment is exactly the private rate of return plus the spillover effect of knowledge creation.

3.1 THE PRIVATE RATE OF RETURN TO INVESTMENT IN R&D

*As all economics data files have weaknesses – measurement error, unmeasured variables, sample survey quirks – and all model specifications are questionable, contaminated by data mining, any ‘finding’ ought to be replicated on several data sets and under ‘plausible’ model specifications before one accepts it as valid
(Freeman, 1989, p. xi)*

Hall et al. (2010) review the econometric studies on the private rate of return to investment in R&D. This will be our starting point. Their review has a thorough discussion of theory behind the production function, measurement and econometric issues in applied work. They also provide tables that summarize the private rate of return to R&D investment based on selected studies,

and they find the majority of estimates to be around 20-30 %. In this review, we put less emphasis on the theory, econometric and measurement problems, and instead we concentrate on whether work since the review can confirm that the rate of return is 20-30 %. We are concerned with whether this rate of return varies across industry, countries, ownership and R&D intensity. It is not to say that the literature has ended with developing new methods or improving measurement; several papers address these issues, but a large part of the literature studied deals with the heterogeneity across types of firms.

The basic idea behind the production function is to treat R&D investment as capital. This is because R&D investment creates an expectation for a future stream of returns just like other capital types; then, it is possible to estimate the rate of return. The typical parameter estimates are “internal” rate of return on R&D investment or the output elasticity of R&D. The former is a measure of the discount rate that makes the net present value of all cash flows from an investment in R&D equal to zero, while the latter measures the percentage change in output when R&D stock increases by one percent. Sometimes in the literature, the output elasticity or the rate of return to R&D is the excess earned over labor and capital. It is the excess over primary inputs (i.e., labor and capital) when they contain R&D personnel and R&D equipment, respectively.

The output elasticity and rate of return are related. Given the output elasticity, the rate of return is recovered by multiplying by the inverse of the R&D intensity, and vice versa. Most studies estimate the output elasticity, and therefore they make the assumption that it is constant across firms. However, it must be noted that the output elasticity is the share of R&D capital rental in output and therefore is likely to not be identical across firms. Alternatively, one can estimate the rate of return directly. If R&D investments earn a normal rate of return, it should be constant across firms ex ante. However, it is the ex post rate of return that is estimated,

and there is no reason to expect that this should be constant across firms. First, depreciations are varying across firms and second, systematic differences in risk across firms exist, and the required rate of return differs because of this. The decision is difficult, and below we report estimates on both types. In many cases, it seems to matter little whether we choose to estimate the output elasticity or the rate of return. Converting the output elasticity to rate of return by the mean or median rate of R&D to output gives close to similar results.

In their review, Hall et al. (2010) present estimates of the private returns to R&D from a large number of studies. The authors conclude that the estimates of the rate of return in developed economies in the second half of the century might be as high as 75 per cent and strongly positive, but most of the estimates are between 20 and 30 per cent. Concerning the output elasticity of R&D, the range is from 0.01 to 0.25 and centered at 0.08. We can compare these estimates with the results from our systematic search. Table 3, which is similar to the tables in Hall et al. (2010), lists the studies that estimate the rate of return or the elasticity of substitution. We do not attempt to compute the rate of return from elasticities from the R&D intensity. Only if the authors themselves provide measures of both the rate of return and output elasticity is it in the table.

As can be seen from Table 3, the results are very much in line with the review by Hall et al. (2010). Output elasticities range from zero to 0.25, and the rates of return range from 3 to 66 %. In the table, we have concentrated mostly on panel data estimators, e.g., controlling for firm heterogeneity. The majority of the reviewed papers also add pooled results, and those find higher rates of return than panel data. However, panel data are more robust towards omitted variables like managerial quality, which is one explanation for the lower estimate of rate of return. Another reason is that there is not sufficient variation in technological opportunities over time relative to measurement errors. But the studies reviewed cover more than 7-8 years of data,

where technological opportunities could sufficiently vary for identification, and measurement error is less of a problem.

Two meta-studies published as working papers also summarize a huge selection of papers on the private rate of return. *OECD (2015)* summarizes the results from more than 200 papers and seems to be the most comprehensive analysis of output elasticity of R&D. The first part of the paper shows that most studies that were performed in the period from 1950 to 1989 were on US data. Since then, the analysis has spread to many different countries. The typical papers in the 1950s and 1960s used firm or industry data, but country data became widespread as well. They estimate the average output elasticity of R&D to be 0.12, which is comparable with Hall et al. (2010).

Donselaar and Koopmans (2016) measures the impact of R&D on output through output elasticities from 38 studies performed after 1980. The selection of papers is from previous reviews and a search in Google Scholar. The authors find an average elasticity of around 0.08.

A caveat is that some researchers suspect that the literature has a problem with publication bias, which occurs when results with significant effects are more likely to be accepted for publication. The reason is that previously mentioned problems with measurement error introduce attenuation bias in estimated parameters, and insignificant estimates might indicate severe measurement problems and not small rates of return (see Møen and Thorsen [2015]).

TABLE 3.*Private rate of return to R&D*

Study	Sample	Period	Type of estimation	Comments	R&D elasticity	Rate of return to R&D
Bloom et al. (Donselaar and Koopmans, 2016)	US 9000 firm year observations	1981-2001	Instruments and fixed effects	Gross rate	*	21%-39%
Bloch (2013)	Denmark, 2949 firms	1997-2005	Fixed effects		0.20-0.24	*
Bjørner and Mackenhauer (2013)	Denmark 1029 firms	2000-2007	Fixed effects		0.13-0.14	20%-25%
Acharya (2015)	OECD 17 countries 28 industries	1974-1992	Dynamic OLS	Excess rate	*	14%-48%
Fracasso and Marzetti (2012)	OECD 17 countries 28 industries	1971-2004	Dynamic OLS		0.03-0.07	*
Eberhardt et al. (2012)	10 countries 12 manufacturing industries	1980-2005	Paneldata with spatial effects		0	*
Bontempi and Mairesse (2015)	Italy, manufacturing 14254 firms	1982-1999	Fixed effects, first and long differences		0.02-0.03	*
Venturini (2015)	US+EU15 less Luxemburg	1980-2003	Dynamic OLS		0.14	*
Bontempi and Mairesse	EU 1129 firms	2006-2007	Structural model		0.05-0.25	*
Ortega-Argiles et al. (2015)	US+European 1809 firms	1990-2008	Fixed effects		0.05-0.09	*
Añón Higón and Manjón Antolín (2012)	UK, manufacturing 465 firms	2002-2006	Structural model		0.05-0.24	3%-40%
Ortega-Argiles et al. (2014)	US+EU 1809 firms	1990-2008	Fixed effects		0.06-0.10	*
Belderbos et al. (2014)	Dutch, 4038 firms	1995-2003	Fixed effects	Decreasing in R&D	*	45%-51%
Doraszelski and Jaumandreu (2013)	Spain, manufacturing 1870 firms	1990-1999	Structural model		*	10%-66%
Cincera and Veugelers (2014)	US+EU 1034 firms	2000-2011	Fixed effect		-0.15-0.13	*

Heterogeneity in the effect of R&D investment

Several papers investigate variation in the effect of R&D investment on productivity across types of firms. An important dimension is technological opportunities, which is likely to vary across industries. High-tech sectors are associated with frequent and radical innovation, and low-tech sectors are associated with scarce and incremental innovations. Therefore, we expect that the output elasticity is higher in high-tech sectors, implying that the share of R&D capital rental in output is much larger. The net rate of return is, however, still expected to be constant across sectors *ex ante*, but *ex post* it might differ. Here it is also important to note that the depreciations are important because they might be higher in high-tech sectors, and therefore the gross rate of return might be higher in high-tech sectors. García-Manjón et al. (2012), Ortega-Argiles et al. (2015) and Kancs and Siliverstovs (2016) all provide evidence that high-tech sectors are earning a higher return. Kancs and Siliverstovs (2016) finds that the average output elasticity is 0.25 for high-tech firms and 0.05 for low-tech firms. Ortega-Argiles et al. (2015) also finds support for a higher elasticity in high-tech manufacturing (again based on the technological intensity) compared to other manufacturing. The difference is, however, rather small between the industries when compared to the estimates in Kancs and Siliverstovs (2016). One reason is that Ortega-Argiles et al. (2015) apply fixed-effects estimators. This is a good thing to do in case of unobserved heterogeneity, but it might also wipe out technological opportunities, which are important to identify inter-industry differences in output elasticities. Several papers include services separately, which is an interesting distinction, as the service sector is becoming more and more important, not only in terms of employment growth but also in terms of productivity growth. Ortega-Argiles et al. (2015) find that the output elasticity of R&D in service firms is overall of the same size as in manufacturing. Finally, García-Manjón and Romero-Merino (2012) find that R&D investment increases firm growth in medium- and high-tech manu-

facturing, and they find that knowledge-intensive firms in the service sector benefit more from R&D investment than less knowledge-intensive service firms. Therefore, evidence exists that R&D investment in the service sector generates high rates of return and output growth.

The estimates of Doraszelski and Jaumandreu (2013) of the net rate of return across manufacturing industries vary from 10 % in food and beverages to 66 % in metals and metal products. The classification of industries is not in high- or low-tech industries, but the results point at huge heterogeneity within manufacturing. In the paper, they apply a new estimation method, where the firm bases the decision of investment on observed productivity levels. Therefore, investment is a signal of productivity, and productivity can be backed out of the production function and correlated with R&D investment. The method does not require the R&D stock and controls for endogeneity between variable input factors and productivity. Doraszelski and Jaumandreu (2013) also shows that the new method produces much lower rates of return than the traditional methods with R&D stock. The average rates of return in their data with the new and old method is 40 and 80 %, respectively.

Añón Higón and Manjón Antolín (2012) look at ownership heterogeneity. They suggest that being a multinational company might give you some benefits, which domestic firms do not have. The mediating effect comes from lower cost in internationalization of R&D and the ability to learn from global knowledge stock. In the paper, they find that the rate of return to R&D for foreign multinationals, British multinationals and domestic firms are 15, 13 and 2 %, respectively, which demonstrates a much higher rate of return for multinationals. Belderbos et al. (2014) explore in-house R&D investment versus sourced R&D from subsidiaries abroad and their effect on productivity. The advantage for the multinational firm is that it can perform R&D in countries providing a rich technology. If this is the driving motivation for sourcing R&D, it can provide complementarities to in-house R&D. In their analysis,

they divide the sample into firms in leading and laggard industries. Laggard industries might benefit more from a rich technology, while leading industries do not face this opportunity. The results show that rate of return on domestic R&D is 45 percent for small levels of R&D in the leading industries, and 51 percent in laggard industries – in the latter case, there is decreasing R&D intensity. The rate of return on foreign R&D is insignificant in the leading industries, but it is large and significant in laggard industries (i.e., 97 %) but decreasing in R&D intensity.

Firm age and size have also received a lot of interest in the literature, but no clear conclusion has emerged on their role. Young firms might differ from large and incumbent firms for a number of reasons. First, one difference between small and large firms is the financial costs they face. Small firms face higher costs and therefore a higher required rate of return. Second, the firms have different abilities to take on R&D investment. Large firms can better appropriate knowledge, which is often complicated and expensive. Third, the difference might relate to flexibility and the type of innovation. Large firms lack the ability to make radical innovations, and they are less flexible mainly because of their size and organizational structure. In a study of young leading innovators (yollies), Cincera and Veugelers (2014) find that the rate of return of R&D for yollies in the US and EU is slightly higher than for all firms in the sample, though not statistically different. Note that a yolli is a firm born after 1976 in the sample of top innovators in the US and EU. Allowing for differences in the rate of return to firms in the US and EU reveals that the yollies in the US have a higher rate of return (12 %) than other leading innovators in the US; also, the yollies in the EU have the same rate of return (0 %) as other leading innovators in the EU. Therefore, evidence is not conclusive on the age and size of the firm. The paper also points at another interesting discussion: There are cross-country differences in the effect of R&D on output. Allowing for differences in the rate of return to R&D between firms based in the US and EU, the paper

reveals that a much higher rate of return exists in the US compared to the EU. In their sample, firms in the EU earn a rate of return that is not statistically significant from zero.

Some studies also focus on country differences, which is very interesting. Erken and Es (2007) decompose the difference in R&D intensities for the US and EU15 and find that industry structure only explains a minor part of the difference. Instead, they find that it is within industries, in particular services, that the US and EU15 countries differ. In the paper, they contribute the differences in R&D intensities to various different factors, many of which can be influenced by the government. They conclude that fostering competition and deregulation in combination with a more rigorous IPR regime is the best way forward for Europe. However, another reason might be that the rate of return differs across countries, i.e., because the rate of return is larger in the US can explain a higher R&D intensity. Ortega-Argiles et al. (2014) estimates the rate of return with firm data for the US and EU15 separately and find that the elasticity is larger in the US compared to EU for firms both in manufacturing and services, which explains the higher R&D intensity in US firms. Cincera and Veugelers (2014), who directly estimate the rate of return, show that the rate of return is higher in the US. It could be that some countries are having more difficulties of translating R&D investment into productivity than other countries. Cincera and Veugelers (2014) points at differences in the innovation systems of countries and in particular on the ability of young US firms to grow to very big firms in the US contrary to the EU. Meanwhile, Ortega-Argiles et al. (2014) argue that some countries have a higher ability to make the necessary organizational change that makes R&D investments more productive.

Is there a diminishing return to R&D? As most papers are focused on the average effect, the typical estimates using production functions do not provide an answer to this question. However, a few papers try to investigate the relation between the R&D intensity and out-

put/productivity. In Kancs and Siliverstovs (2016), the connection between productivity and R&D investment depends on the R&D intensity. They find that the output elasticity is negative at very low R&D-intensity, but it rises with R&D-intensity, although at a decreasing rate. Therefore, the marginal effect of R&D (rate of return) is only positive until a certain critical mass of R&D is reached, and it is mostly positive; at higher rates of R&D-intensity, it begins decreasing. The decrease in the marginal effect is quite small and only for firms with extremely high levels of R&D-intensity.

These findings are at the firm level. The macroeconomic literature also points towards a diminishing rate of return to R&D. The last forty years of investment in R&D and education has increased much more than productivity. The rise in investment in knowledge and the lagging productivity growth has raised some concern about whether knowledge is a simple input like labor and capital, despite the knowledge component. Belderbos et al. (2014) allow for a diminishing rate of return to R&D. They find that firms in leading industries have a constant rate of return, whereas firms in laggard industries have a diminishing rate of return.

Eberhardt et al. (2012) focus on the influence of spillover effects (see below) on the private rate of return. A spatial error structure accounts for spillovers across countries and industries. This has an impact on the estimated elasticity as it drops and becomes insignificant. When spillovers exist, it might be more beneficial to invest in R&D if R&D investment complements spillovers. Therefore, it is important to include spillover effects whenever estimating the private rate of return. This phenomenon is known in the peer-effects literature as the “reflection problem” (Manski, 1993).

Business cycle

The rate of return might also be related to the business cycle and can explain some of the huge differences across studies. On one hand, the required rate of return might be much higher during recessions, which can

explain the pro-cyclicality of R&D investment (Hud and Hussinger, 2015). On the other hand, opportunity cost could be low in recession, and therefore investment might be high (Añón-Higón et al., 2014). In Aghion et al. (2012), the credit-constrained firms' investments in R&D are pro-cyclical, and non-credit constrained firms are counter-cyclical. Turning to the rate of return across business cycles, Anon-Higon et al. (2014) find that the rate of return is counter-cyclical. First, they find that R&D-performing firms earn a premium that is much higher in recessions compared to non-R&D performing firms. Note that this discussion suggests that the rate of return is not a scientific constant; instead, it is likely to vary, for example, with time, industry and country.

Denmark and policy related literature

For Denmark, we have found a number of studies that estimate the rate of return. FI (2015) estimates the rate of return from different types of R&D within the firm. They find that the output elasticity of total R&D is 0.15-0.17, and the rate of return is between 17-22 %. In-house R&D and sourced R&D do not provide different rates of return. Bjørner and Mackenhauer (2013) estimate a model with R&D capital and find output elasticities around 0.12 and that the rate of return is between 20 and 25 % for firms in Denmark.

FI (2012) estimates the rate of return for Denmark to be 34 %. The estimate is quite high compared to FI (2015) and Bjørner and Mackenhauer (2013) and could be due to not accounting for other drivers of productivity, including employee skills and unobserved heterogeneity, i.e., quality of management. More interestingly, in the same study, they estimate similar models on similar data for Norway, Sweden and Finland. The cross-country comparison shows that the rate of return is highest in Denmark.

Summary

From the discussion, it is clear that private return to R&D varies quite a lot, whether it is estimated as the output elasticity of R&D capital or net rate of return of

R&D investment. Overall, the results are in line with previous reviews like Hall et al. (2010). Here it is found that the majority of studies find an output elasticity between 0.01 and 0.25 and a rate of return around 20-30 %. However, the chapter also reveals a great of heterogeneity in the estimated parameters. Industry, business cycles, countries, etc. all show that the rate of return greatly varies. Some of the studies look into whether the rate of return is diminishing. While the very limited evidence says “yes”, it is possibly only at very high levels of R&D intensity. The average effect of R&D investment for Denmark is of a similar size.

3.2 THE SOCIETAL RETURN TO R&D

The secrecy of business is on the whole diminishing, and the most important improvements in method seldom remain secret for long after they have passed from the experimental stage
(Marshall, 1920)

In general, R&D generates two types of spillovers, according to Griliches (1991). A firm can use knowledge created by another firm with no cost or with less cost than the value of knowledge. This is disembodied or knowledge spillover. When a firm purchases products embodied with the knowledge, the price might not reflect the user value of the product. This is embodied or rent spillover. In this review, we concentrate on the disembodied spillover. Embodied spillover relates to adoption of new capital. We cannot compute the rate of return or output elasticity of R&D from embodied spillovers, and the results are not comparable. This is not to say that embodied spillovers are unimportant, actually, some authors consider it the most important. For that reason, we concentrate on the disembodied or knowledge spillover in this section.

Knowledge spillovers have been very important from a growth perspective, and the societal rate of return to investment in R&D is the private rate of return to invest-

ment in R&D plus the spillover effect of that knowledge to other firms. From a policy perspective, this is one of the main reasons to promote R&D investment. Knowledge spillovers come from other firms in the same industry, other firms in other industries and even other firms in other countries. It might also come from public research or from public funding of R&D, which is the topic in chapters two, three and four. Here we concentrate on the estimates of the effect of other firms R&D knowledge stock.

Hall et al. (2010) review econometric studies of societal return to R&D investment. The cornerstone again is the production function, which augmented with a measure of “other firms” R&D investment can generate an estimate of societal rate of return. The extension of the production function to include other firms’ R&D stock is supposed to catch the knowledge spillover. The societal effect of R&D investment is then the private rate of return plus the rate of return on other ‘domestic’ firms. Spillovers also occur internationally and add further benefits to R&D investment. Not all other firms’ R&D stock is relevant for a firm’s productivity. Some knowledge simply does not generate a spillover to a particular firm. Therefore, it is necessary to specify the knowledge transfer channel. This is extremely difficult, because we rarely observe knowledge flows. In chapter five, we discuss one of the most important channels: labor mobility. Social network data would be extremely useful. That data records the interaction between agents, which in this case is firms. Most of the studies in our review weighed other firms’ R&D knowledge based on technological proximity, input-output relations, geographical distance or a combination of the three channels.

In the empirical studies reviewed in Hall et al. (2010), the relevant R&D stock is a weighted sum of other firms’ R&D stock. Some of the most typical weights come from trade data. The idea is that contact to customers or suppliers increase the chance of knowledge transfer. Alternative weights come from estimates of technological

similarity, which often use patents to construct a technological position of firms (Jaffe, 1986) or geographical proximity. The shortcoming of applying patents is that it only applies to patenting firms. The trade-based weights are sometimes problematic because the trade relation might also pick up other things, i.e., rent spillover.

The knowledge spillovers that are estimated in these studies are all based on output elasticities. It is possible to convert these to rates of return like above. The social rate of return is obtained by adding the private rate of return and the sum of the rate returns to other receiving firms. The results from Hall et al. (2010) are that spillovers are often twice as large as private rates of return. This

means that the societal rate of return is in the range from 70 to 100 %. However, as Hall et al. (2010) note, it is imprecisely estimated. Donselaar and Koopmans (2016) confirm the high social rate of return in their meta-study.

Table 4, which is similar to the tables in Hall et al. (2010), lists the studies that estimate the spillover of R&D. We do not attempt to compute the rate of return from elasticities by the R&D intensity. We only present them if the authors themselves provide measures of both the rate of return and output elasticity.

The results are not qualitatively different from Hall et al. (2010) and show a large variation in knowledge spillovers.

TABLE 4.

Spillover effect of R&D

Study	Sample	Period	type of estimation	weights	spillover
Bloom et al. (2013)	US 9000 firm year observations	1981-2001	Instrumental variable and panel	Tech+ geography	Rate of return 20%-46%
Cardamone (2012)	Italy, manufacturing 1203 firms	1998-2003	NL3SLS, instrumental variables	Tech+ geography	Output elasticity 0.08-0.32
Venturini (2015)	US+EU15 less Luxemburg	1980-2003	DOLS	Trade	Output elasticity 0.04
Acharya (2015)	OECD 17 countries 28 industries	1974-1992	Dynamic OLS	None	Rate of return -16%-128%
Bloch (2013)	Denmark 2949 firms	1997-2005	FE	Tech+ geography	Output elasticity 0-0.10
Fracasso and Marzetti (2012)	OECD 17 countries 28 industries	1971-2004	Dynamic OLS	Trade	Output elasticity 0.13
Bjørner and Mackenhauer (2013)	Denmark 1029 firms	2000-2007	Fixed effects	Tech+ geography	Output elasticity 0-0.05
Bernstein and Nadiri (1989)	US, selected manufacturing industry 48 firms	1965-1978	Random coefficient	None	Rate of return 9%-16%

Industry spillovers

Bernstein and Nadiri (1989) find that spillovers vary with industry. They estimate the spillover effect in four manufacturing industries and relate the differences in spillovers across industries to cost decline, factor-bias and capital adjustment, which are likely to differ across industries. The social rate of return is estimated to vary from 9 to 16 %, and the spillover effect is positive and larger than the private net rate of return in all industries. Similarly, Acharya (2015) estimate a model where other firms' R&D stock is not weighted together, but the ten most R&D intensive industries' R&D stock enters the production function. This allows a differential effect of spillovers for different industries. The data is industry data on 17 OECD countries. They find that inter-industry spillovers substantially vary across industries. The spillover to the rest of the economy of the R&D stock varies from -16 to 128 %. The average inter-industry spillover effect to the rest of the economy is 16 %. The huge variation for different industries to the rest of the economy generates some doubt on most of the estimates in the literature, where it is assumed that a Euro spent in metal and metal products has an identical spillover effect to a Euro spent in the pharmaceutical industry.

Cardamone (2012) estimates a production function with Italian micro data and includes other firms' R&D stock in the production function. He applies two measures of proximity based on technology and geography and a combination. The spillover effect, measured by output elasticity, is between 0.07 and 0.32. The lower bound applies weights based on technological similarity.

Bloch (2013) also estimates, with Danish micro data, the spillover from other firms based on the same two different weighting schemes: technology and geography and a combination. The weights are technological proximity computed based on scientific interest. The spillover is largest for technological proximity, 0.10, and insignificant for geographic spillovers.

International spillovers

Spread of knowledge is not limited to within a country. Foreign investments in R&D benefits domestic firms. The literature often finds that the spillover from foreign R&D stock is positive (see Hall et al. [2010]). A huge part of this literature focuses on the catching up of countries and absorptive capacity. In the context of development economics, these are important issues. Our review is mainly on developed countries, and we focus on a few studies that involve OECD countries. Venturini (2015) looks at the US and the EU15 countries in the period 1980-2003. The transmission channel of foreign R&D is trade, and he finds that the return to foreign R&D is positive overall, and the output elasticity of foreign R&D is 0.04. Introducing foreign R&D in the model lowers the output elasticity of domestic R&D, which points to the importance of controlling for international spillovers in gauging the effect of domestic R&D. Acharya (2015) finds the rate of return of international spillovers to be around 4 percent. The transmission channel is once again trade. Fracasso and Marzetti (2012) question whether trade-related spillovers are localized or come from a global pool of knowledge for 24 OECD countries for 1971-2004. They find that the best fitting model has localized trade spillovers, and that the spillover decreases with geographical distance.

Denmark and policy papers

Bloch (2013), mentioned above, finds that the output elasticity of spillover in Denmark varies from 0 to 0.10, depending on the chosen spillover channel. The spillover based on geography is 0, which he argues is due to the small size of Denmark. He argues that Denmark is too small to identify the geographical spillover. Bjørner and Mackenhauer (2013) estimate the spillover effect from other firms' R&D stock using technology (scientific interest) and geography proximity and a combination of both. The output elasticity of spillovers varies from 0 to 0.04 and is highest for geographical proximity or the combination. In their study, the social rate of return varies from 26 to 29 %, and the spillover accounts for 5 to 7 %. The small spillover could be because the number of potential receivers is small in Denmark.

Business stealing

Before wrapping up, we note that a third spillover exists, and it relates to the entry and exit of firms/products and the business stealing/product market rivalry of R&D. We know that aggregate productivity growth depends on the entry and exit of firms (creative destruction). Since R&D generates new products, and other products become obsolete, we discuss results on product market rivalry and business stealing. Bloom et al. (2013) and Czarnitzki and Kraft (2012) are examples. In Czarnitzki and Kraft (2012), incoming spillovers from competitors have a positive impact on firm sales, but the average rate of ingoing spillovers (in the same industry) has a negative impact on sales. The latter impact is a measure of business stealing in the industry. Hence, operating in an industry with many 'outgoing' spillovers has a negative impact, but this effect is less than the spillover from ingoing spillovers (knowledge spillover). Bloom et al. (2013) also model two types of spillovers: a knowledge spillover from firms with similar technologies (measured by patenting) and product market rivalry with firms with a similar product line of business. The paper finds that knowledge spillovers dominate market rivalry, so the social rate of return is at least twice as high as the private rate of return. Hence, both papers find a negative spillover from business stealing, but it is not in the same order of magnitude as the knowledge spillover effect. Hence, both papers find a higher social value of R&D than private value.

The business stealing effect is also important in Harrison et al. (2014), where they estimate the effect of private R&D investment on employment. The paper discusses another important aspect of R&D innovation, which is the reallocation of inputs due to changes in the competitive position of firms. They find that firms with active R&D create employment and that a third of this employment comes from competitors. It is not only reallocation of R&D employees due to movement of R&D in the economy, but it is the movement of all types of employees.

Summary

Given the enormous variation in spillover estimates, the societal return is very uncertain, except that it is likely to be positive and higher than the private return; this creates a foundation for public intervention to correct the market failure, which is covered in the next chapter. First, most studies rely on indirect measures of spillover and omit other important variables in the analysis, which might bias the results mostly upwards. Our suggestion based on the literature is to pursue direct modelling of transmission mechanisms like in chapter five on labor mobility in this report. What is the macroeconomic effect of R&D investments? Taken from the productivity literature, it seems to be extremely large. Given the enormous spread in knowledge spillover, it is hard to say what it is for Denmark. The studies by Bloch (2013) and Bjørner and Mackenhauer (2013) point at results in the lower end. This is also to be expected as the potential number of receivers (firms) is quite small in a country like Denmark. This is not to say that R&D policies are less important in Denmark, because business stealing and product market rivalry effects are likely to be small as well. Ultimately, as of yet, we have no results on international spillovers received by Danish firms.

4. Public funding of R&D investment

- 1. Introduction
 - 2. Methodology
 - 3. The effects of private R&D on firm performance and economic growth
 - 4. **Public funding of R&D investment**
 - 5. Public research, education and R&D labor market
 - 6. What is the effect of knowledge transfer on firm performance or growth?
 - 7. Conclusion
- Literature

The prevalence of innovation market failure and underinvestment in technology implies the need to establish a long-term institutional framework for the support of basic research, generic-enabling research, and commercialization.

(Martin and Scott, 2000, p. 445)

Economic argument for public R&D funding

From a Schumpeterian perspective, R&D and innovation determine the main drivers for technological change in a society (Schumpeter, 1942). Similarly, in a neo-classical tradition, technological progress is the source for a sustainable growth (Solow, 1956). Regarding the technological progress in a society, the private sector plays an important role for the discovery and diffusion of new knowledge and technologies. However, due to the risky and uncertain nature of R&D projects and the public good characteristics of knowledge (non-rival and only partially excludable), firms tend to under-invest in R&D activities (Arrow, 1962; Nelson, 1959). Given this classic public-good problem, R&D and innovation are subject to market failure (Martin and Scott, 2000; Romer, 1990), which means that the investments in R&D activities from the private sector are below the socially optimum level. Jones and Williams (1998) derive a simple analytical growth model and also perform a structural estimation of their model. They show that socially optimal R&D is between two to four times above current investments.

There are many reasons for this gap between the private and social optimal level. One important reason is that the private rate of return of R&D is lower than the social return as firms cannot fully appropriate the returns of their R&D investments (Griliches, 1979; Griliches et al., 1991). This might be caused by the existence of externalities due to knowledge spillovers. Furthermore, financial market imperfections, informational asymmetries between investor and inventor, moral hazard problems between owner and management, barriers to entry and exit or shortage of high-qualified personnel (Cerulli, 2010; Hall, 2002; Martin and Scott,

2000 and chapter 5 in this review) might lead to investments in R&D activities from the private sector being below the socially optimum level.

This gap between the social and private optimum in R&D investments has been the rationale for governments to engage in the support of private R&D.

Influenced by the above mentioned reflections that innovation contributes to higher and sustainable growth rates, governments have introduced various policy instruments to promote R&D in the private sector. These policy instruments are designed to reduce the gap between the social and private optimum in R&D investments and stimulate innovation in the private sector. Such policy instruments include direct public subsidies, tax incentives, lower interest rates and modifications to intellectual property or anti-trust and completion laws. Further categories for public policies entail support of formal R&D collaboration (this chapter) as well as support of a university system and formation of high-skilled human capital (chapter five).

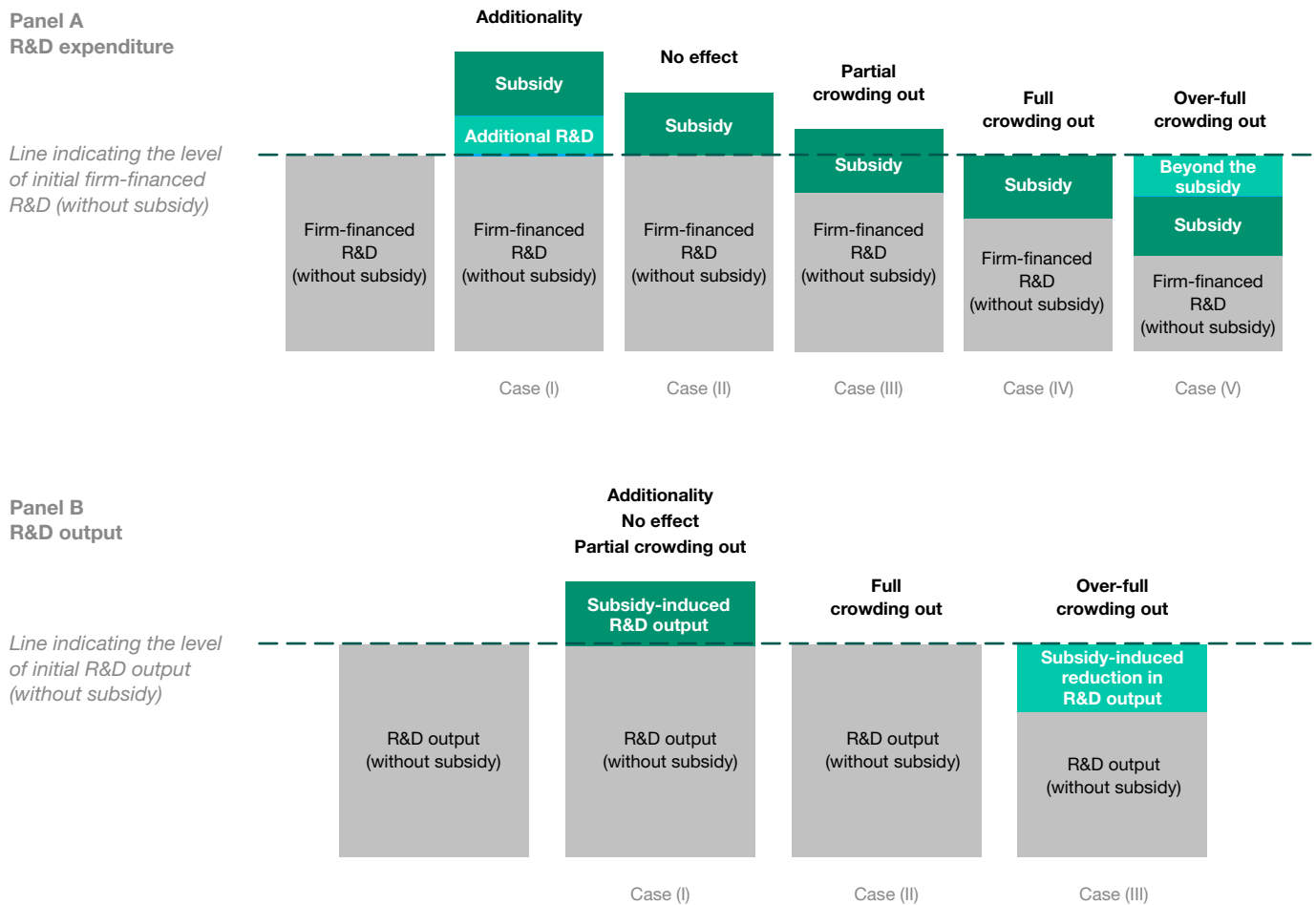
Government funding has limitations in financial resources and involves taxpayers' money; hence, it is important to know if these resources for public funding are used in an efficient and effective way (Beck et al., 2016; Veugelers, 2016). In particular, it is of interest whether or not public funding for private R&D projects leads to additional private investments (crowding-in) or substitute private investments (crowding-out). In their review of 33 empirical studies, David et al. (2000) show that two thirds of the papers provide evidence for complementarity and one third for substitution. They show that evidence for substitution is more often found in papers that use disaggregated US data. According to David et al. (2000), a key problem with the literature is, however, the poor identification of causal effects.

Further, policy makers are interested to know if subsidized R&D is as effective as non-subsidized R&D. Regarding the stimulating effects of public support,

the literature differentiates between input additionalities (e.g., R&D investments, R&D personnel) and output additionalities (e.g., sales with innovative products, patents, labour productivity). The following figure by Dimos and Pugh (2016) illustrates the different forms of additionalities.

FIGURE 1.

The possible effects of R&D policies on (a) R&D expenditure (b) R&D output.



4.1 WHAT IS THE EFFECT OF PUBLIC FUNDING OF RESEARCH ON PRIVATE R&D INVESTMENT OR FIRM PERFORMANCE?

The two main public policy instruments available for governments to support private R&D projects are direct public funding (i.e., subsidies) and tax incentives. Tax credits are considered to be the more market-oriented response to market failure as it leaves the decision of which projects to conduct and the underlying timing decisions to the private sector. According to Hall and Van Reenen (2000), there might be several drawbacks, since fiscal incentives are simple and ineffective in stimulating private R&D spending, and the response elasticities are so low that it would take a substantial tax amount to generate the socially desirable amount of R&D spending. Reviewing the pre-2000 literature on tax incentives, Hall and Van Reenen (2000) conclude, however, that despite some considerable variation, tax credits have a significant positive effect on R&D expenditures (see also Becker [2015, p. 922]). This means that the additionally induced private R&D spending is larger than the foregone tax income. Public subsidies for the private R&D sector are designed to increase private R&D investments and hence to promote projects that would have not have been conducted without public support. Firms usually apply with a project description at an agency to receive public funding. Sometimes, these public policies are designed to stimulate particular forms of investment for different firm groups. For example, there are special programs for small and Medium Enterprises SMEs and young firms. Overall, these direct public subsidies are intended to increase additional private R&D investments and to reduce the under-investment in R&D in the private sector. To achieve this objective, it is important to limit the risk of funding R&D projects that would have been undertaken and financed by the private sector anyway.

Generally, for the evaluation of the effects of public financial support programs, it is worth mentioning that due to the varied design of subsidy programs (e.g., targeted, screening projects, requiring collaboration or not, firm size, etc.),

comparing results is somewhat difficult. For tax incentives, if the marginal R&D price is computed, the situation is somewhat different, as there is rarely any other screening. So, contrary to public subsidies, tax incentives are easier to compare with a single price elasticity measure.

Main questions

This chapter considers the effects of public funding for private R&D. Chapter five deals then with the effects of investments in the public R&D sector. This section deals with the following main questions:

- Does public funding crowd out private R&D or does public funding stimulate private R&D; put differently, is public funding a complement or substitute for private R&D?
- Which types of input or output additionalities are created by public funding?

Reviews on the effects of public funding for private R&D

Econometric studies in this field are subject to certain methodological problems, but they suggest that the economic benefits from public funding for private R&D are quite substantial. Important reviews in this field include Arvanitis (2013), Becker (2015), David et al. (2000), Dimos and Pugh (2016), Klette et al. (2000) and Zúñiga-Vicente et al., (2014). Increasing governmental support for private R&D has not only given rise to a large and growing number of empirical evaluation studies in the academic literature but also to a steadily growing interest of policy makers in the evaluation of public support. Fahrenkrog (2002) and Czarnitzki et al. (2015) provide comprehensive policy reports on public innovation support at the EU level; Jaumotte and Pain (2005) and Fosse et al. (2014) provide reports for the OECD and for the Danish research and innovation support system, respectively. Despite the evaluation of the effectiveness of public R&D support policies based on different indicators, these reports also try to assess the effects from a social welfare perspective. This section evaluates and summarizes the effects of two specific public support policies: direct public R&D subsidies and tax incentives.

TABLE 5.*Effects of direct public funding of research on private R&D investment or firm performance*

Table: Own adaptations relying on various sources (Arvanitis, 2013; Becker, 2015; Dimos and Pugh, 2016; Zúñiga-Vicente et al., 2014)

Study	Data	Period	Method	Main finding
Direct public R&D subsidies				
Dimos and Pugh (2016)	52 micro-level studies	After 2000	Multi-Regression analysis	Rejection of crowding out of private R&D investments by public subsidies. Elasticities of less than .01. Additionalities increase over time indicating institutional learning.
Hud and Hussinger (2015)	CIS Germany firm-level data	2006-2010	Nearest neighbor matching OLS	Positive effect of R&D subsidies on SMEs' R&D investment. Temporary crowding out effect during crisis caused by reluctant innovation investment behavior of the subsidy recipients rather than by Germany's counter-cyclical innovation policy
Duguet (2004)	French survey data	1985-1997	Kernel matching estimations	Positive effects on private R&D expenditures and sales
Carboni (2011)	Italian survey data manufacturing firms	2001-2003	Nearest neighbour matching	Positive effects on R&D investment
Gonzalez and Pazo (2008)	Spanish survey data	1990-1999	Matching procedure (biascorrected nearest neighbour estimator)	Positive effects on private R&D expenditures; especially for small firms and firms operating in low-technology sectors
Beck et al. (2016)	Swiss CIS	1999-2011	Nearest neighbour matching Tobit models IV approach Lag structure	Positive effects on private R&D Positive effects on radical innovation Collaboration does not enhance the subsidy effect Similar effect sizes of policy-induced R&D and private R&D.
Aerts and Schmidt (2008)	Belgium survey data	1998-2004	Nearest neighbour matching conditional difference-in-difference estimation	Positive effects on R&D expenditures Positive effects sales
Hussinger (2008)	German CIS	1992-2000	Parametric (Heckman) and semiparametric two step equation selection models	Positive effects on R&D expenditures per employee Positive effects on sales of new products
Cerulli and Poti (2008)	Italian survey data	1998-2000	Different matching approaches Heckman selection model	Overall positive effects on R&D expenditures

Czarnitzki and Hussinger (2004)	German CIS	1992-2000	Nearest neighbor matching. OLS.	Positive effects on R&D expenditures Positive effects on patents
Czarnitzki and Licht (2006)	German CIS	1994-2000	Matching and OLS	Positive effects on R&D intensity Positive effects on innovation intensity
Czarnitzki and Lopes-Bento (2014)	German CIS	1992-2006	Matching	Positive effects on R&D expenditures Positive effects on patents. Nationally subsidized firms (or firms financed from both sources) are more patent-active
Hottenrott and Lopes-Bento (2016)	Belgium CIS	2002-2008	Nearest neighbor matching Tobit models	Positive effects on R&D expenditures, especially in internationally collaborating SMEs Positive effects on marketable product innovations, policy-induced R&D investment is highest for international collaborators as well as for SMEs
Arvanitis et al. (2000)	Swiss CIS	2000-2002	Four different matching methods	Positive effects on innovation performance (six different measures of innovation performance) Magnitude of the subsidy impact positively correlated with the relative amount of financial support
Kaiser (2006)	Danish survey data	1999-2001	Matching approach difference-in-difference model	Weak positive effects on R&D expenditures.
Bloch and Graversen (2008)	Danish survey data	1997-2005	Heckman selection model OLS, IV	Additionalities. 1% increase in public funding yielding 0.08-0.11% increase in private R&D.
Sørensen et al., 2003	Danish survey data	1974-1995	Regression models	Additionalities. Elasticities of 0.062
Tax incentives				
Harris et al. (2009)	Northern Ireland	1998-2003		Long-run user cost elasticity around -1.4
Lokshin and Mohnen (2012a)	Netherlands	1996-2004		Some evidence of additionality for R&D investment (estimated user cost elasticity), however crowding out can be rejected only for small firms
Mulkay and Mairesse (2013)	French data	2000-2007	Dynamic R&D investment demand regression model	Elasticity of -0.4 for the long-run user cost of R&D capital
Czarnitzki et al. (2011)	Canadian data	1997-1999	Nearest neighbor matching	Positive effect on number of new products, sales share of new products, introduction of <i>world</i> and <i>Canadian</i> novelty
Cappelen et al. (2012)	Norwegian data	1999-2001 2002-2004	Selection correction. Two-equation model	Probability increases for products and processes new for the firm. No effects on patents, products new to the market

Yang et al. (2012)	Taiwan data	2001-2005	Panel instrumental variable (IV) and generalized method of moment (GMM)	Positive moderate marginal effects from 0.094 to 0.120 on R&D expenditures
Castellacci and Lie (2015)	Multiple countries	1991-2013	Multi-Regression-Analysis	Positive effects for countries using incremental tax schemes. Positive effects for SMEs. Positive effects firms in service sectors. Effective for low-R&D intensive firms rather high-R&D intensive firms.

Direct public R&D subsidies

Contrary to earlier literature, the more recent empirical literature as summarized in the above mentioned reviews on direct public subsidies reject crowding out and point to significant input and output additionality effects. One reason for the shift in the empirical literature away from substitution effects to crowding-in may be the application of more accurate econometric approaches suitable to control for severe selection issues.

For instance, in their meta-regression analysis on 52 micro-level studies published after 2000, Dimos and Pugh (2016) reject crowding out of private R&D investments by public subsidies. Their findings indicate elasticities of less than .01, meaning that a doubling of the subsidy would lead to an increase in private R&D of less than 1%. Generally, this number might appear low, but it represents the lower bound of the effect size. In addition, as a robust result from a MRA, it emphasizes the robust and substantial contribution of subsidies to increase private R&D investments. However, with respect to output additionality, their analysis could not reveal any statistical evidence of a substantial output additionality created by the subsidy. While this lack of empirical evidence for output additionality may be disappointing for policy makers, this is quite typical for the evaluation of public policies. The authors state,

“individual policies can work in the direction intended but yield quantitatively smaller effects than hoped for (p. 810).” In sum, this meta-regression analysis identifies a representative subsidy effect controlling for several selection bias. These findings emphasize that direct public R&D support does contribute to addressing market failures by increasing both R&D input and output for subsidized firms compared to the counterfactual situation of not having received a public grant. Notably, crowding-out of private R&D investment is clearly rejected.

This result can be important if direct public R&D support is used in a broader counter-cyclical policy in order to sustain private R&D investment during economic crisis (Hud and Hussinger, 2015). In addition, Dimos and Pugh (2016) find that the additionality effects created by the subsidies is increasing over time, which might be influenced by institutional learning. This is also in line with the findings of Klette and Møen (2012), who report that the effectiveness of the policy tool has improved over time.

Applying a matching framework, Czarnitzki and Hussinger (2004), Duguet (2004), González and Pazó (2008) and Carboni (2011) reject crowding out for German, Spanish, French and Italian firms and find that

direct R&D subsidies on average lead to higher private firm investments in R&D activities. Beck et al. (2016) confirm these findings for Swiss firms. Using different robust checks including instrumental variables estimations, they can provide empirical evidence that direct R&D subsidies enhance particularly radical innovations, whereas the additionality effects on incremental innovation remain insignificant. Further, their results indicate that the additional policy-induced R&D investment has similar effect sizes on radical innovation output compared to non-subsidized private R&D. For instance, from their data on Swiss firms, on average, an increase of 10 % in private R&D investment would lead to an increase of 4.4 % in the estimated sales share in radical innovation sales, while an increase of 10 % in the policy-induced R&D would lead to an increase of 3.7 % in the estimated radical innovation output ratio.

The rejection of full crowding out is also supported by various prominent studies using different estimation techniques. For instance, in the case of Flanders and Germany by Aerts and Schmidt (2008) (difference-in-difference approach), Hussinger (2008) for Germany (two step-selection models), and Italy by Cerulli and Poti (2012) (matching approach, selection model and difference and difference estimation).

In terms of output additionality, earlier empirical studies are in line with the above mentioned findings of Beck et al. (2016). These studies provide evidence that subsidies have a positive impact on innovation performance, as measured, for instance, by patent outcome (see, e.g., Czarnitzki and Hussinger [2004], Czarnitzki and Licht [2006]) or novelty sales (see, e.g., Czarnitzki and Lopes-Bento [2014] for a sample of German firms or Hottenrott and Lopes-Bento [2014] for a sample of Belgian firms). In a study on Swiss firms, Arvanitis et al. (2010) confirm the results for improved innovation performance of supported firms with respect to six different measures of innovation performance.

Denmark

For Denmark, Bloch and Graversen (2012) report additionality effects of public R&D funding for Danish firms using a dynamic panel data regression analysis. Using Danish data from 1998 to 2005, Bloch and Graversen (2008) also find additionalities with a magnitude of a 1 % increase in public funding leading to 0.08-0.11 % increase in private R&D. These findings are in line with an earlier study conducted by Kaiser (2006). Applying three different identification approaches, this study reports statistical evidence for the presence of positive effects of R&D subsidization with point estimates of between 0.8 and 0.5 percent. Sørensen et al. (2003) analyses public innovation support, and the study reports a positive and significant effect on private R&D expenditures with an estimated elasticity of 0.062. Additionally, they investigate the indirect long-term effect on productivity from public innovation support and find a positive (although insignificant) point estimate with an elasticity of 0.012. Generally, these estimates are in line with Griliches (1979), who states that there is weak empirical evidence on the relationship between productivity and R&D-related variables. More recent research confirms that this empirical evidence is no longer weak.

Wrap-up

Generally, the studies after 2000 on the empirical evaluation of direct public R&D support clearly lead to the conclusion that there is substantial empirical evidence that public R&D subsidies succeed in stimulating private R&D investment, and there is some empirical evidence that direct R&D support can enhance innovation outcomes, such as patents, innovative sales and R&D employment as well as productivity. Overall, direct public funding of R&D not only complements private R&D in terms of additional R&D investments but also leads to desirable innovation outcomes. To conclude, direct public R&D subsidies constitute an effective policy measure to increase industrial innovations.

Tax incentives

One important issue related to the evaluation of tax credit schemes is the so-called “re-labelling problem” (Hall and Van Reenen, 2000). As a tax credit lowers the price of R&D activities, firms have an incentive to maximise the share of R&D activities that qualify for the tax credit. Consequently, firms intend to move as many expenses into those accounts that qualify for tax incentive schemes. Furthermore, tax credits generally apply to all activities – irrespective of whether they are additional or not.

Hall and Van Reenen (2000) provide econometric evidence of the effectiveness of fiscal incentives for R&D, and the authors conclude that a dollar in tax credit for R&D stimulates a dollar of additional R&D. This implies that, on average, the firms raise the investment with an amount equal to the saved taxes. More recent literature confirms these findings and point to elasticities that can be larger than one. The estimated elasticities depend, however, on the data, model specifications and estimation method (Arvanitis, 2013; Becker, 2015). Becker (2015) summarizes several prominent studies in this field and concludes that fiscal policy measures such as tax credits that reduce the price for private R&D activities are expected to increase private R&D investments. Overall, across the different studies, the average negative elasticities seem to be near unity. Specifically, Harris et al. (2009) report a long-run elasticity of R&D of around -1.4 for manufacturing plants in Northern Ireland, and Lokshin and Mohnen (2012a) find elasticities of -0.8 for firms in the Netherlands. Mulkay and Mairesse (2013) report long-run elasticities of -0.4 of the user capital of R&D for a sample of French firms. Bernstein and Mamuneas (2005) find elasticities of -0.8 and -0.14 for US and Canadian firms, respectively. The lower elasticities for Canada are also confirmed by Baghana and Mohnen (2009). The authors of these studies argue that the lower elasticities for Canada are affected by the dominance of foreign firms conducting R&D, which in turn are not as susceptible to changes in Canadian eco-

nomical conditions as are domestic firms. In the same line, Czarnitzki et al. (2011a) find that R&D tax credits positively affect the decision of whether Canadian firms conduct any R&D at all. Applying a matching-procedure on their dataset covering the years from 1997-99, they further conclude that tax credits are a suitable tool to stimulate additional innovation output. In the case of Norway, Cappelen et al. (2012) report positive effects of tax credits for process innovation and innovations new to the firm. However, according to their analysis, tax credits seem to have no additional effects on innovations that are new to the market as well as patents. Regarding the effects of R&D credits in a transformative country, Yang et al. (2012) provide evidence for positive but moderate effects of R&D tax credits for Taiwan.

More recent literature points out that tax credits are particularly effective in countries that have an incremental scheme, such as US, Japan and France (Castellacci and Lie, 2015a). Additionally, as indicated in their multi-regression analysis, Castellacci and Lie (2015a) show that R&D tax credit schemes are especially effective for SMEs and firms in the service sector. They conclude that tax credits for R&D activities seem to be an effective means for firms with low R&D intensities rather than for highly R&D intensive companies in high-tech sectors. From a policy perspective, given their findings, the authors argue that a tax credit scheme that is designed as an incremental incentive scheme rather supports lagging firms to catch up with the technological frontier in their sector rather than to push the frontier to an advanced technological level.

Wrap-up

The current understanding in empirical research on the effects of tax credits leads to the conclusion that tax credits can stimulate private R&D investments. Tax credits increase the amount of corporate R&D efforts and lower its marginal costs.

4.2 HOW DOES PUBLIC FUNDING DISTRIBUTION AFFECT KNOWLEDGE, PRIVATE R&D INVESTMENT OR FIRM PERFORMANCE?

As public financial resources to stimulate private R&D are limited, and the funding for public support originates from taxpayers' money, it is of special interest to know where the effects of public funding creates the most additionalities. These questions are part of the current debate in the literature. A general consensus in the empirical evaluation has not been reached yet, but recent studies point out to some trends. This section deals with the distribution of public funding, and a special interest is devoted to the design of effective subsidies or tax incentive schemes. From a policy perspective, policy makers are interested in finding answers to questions such as the following:

- Should funding be attributed to small or large firms?
- Does the requirement to collaborate for the receipt of public support matter?
- Is the source of funding (regional, national, transnational) important?

TABLE 6.

The effects of distribution of public funding for private R&D investment and firm performance

Study	Data	Period	Method	Main finding
Tax incentives				
Elschner et al. (2011)	EU member	2006-2007	Simulation model	Design of tax scheme is important, i.e. volume based vs incremental
Castellacci and Lie (2015)	Multiple countries	1991-2013	Multi-Regression-Analysis	Sector affiliation matters Additionality stronger for SMEs Additionality stronger for incremental schemes
Lokshin and Mohnen (2012)	Dutch CIS, Statistics	1996-2004	Instrumental variable Simulation	Some evidence for additionality in R&D. Crowding out rejected only for small firms
Subsidies and R&D collaboration				
Busom and Fernán-dez-Ribas (2008)	Spanish data	1990-1996	Different regression models	Subsidy enhances the probability that a firm engages in collaboration with a public research institute or a private firm
Czarnitzki et al. (2007)	Finish and German CIS	1994-2000	Matching approach Seemingly unrelated probit models	Subsidized collaboration increases patents, and sales
Hottenrott and Lopes-Bento (2014)	Belgian CIS	2002-2008	Matching approach Treatment effect analysis	Higher treatment effects in terms of R&D spending and market novelties of international collaborating SMEs.
Beck et al. (2016)	Swiss CIS	1999-2011	Matching approach Treatment effect analysis	Some negative effects of the requirement to collaborate on innovation outcomes depending on partner type and degree of innovation novelty
Subsidies and SMEs				
Lach (2002)	Israeli data	1990-1995	Regression (Pooled) Difference-in-Difference	Mixed results. Additionality for small firms. Substitution in the short-term, but additionality after the first year.
Kaiser and Kuhn (2012)	Danish data	1990-2007	Matching approach Difference-in-Difference	No statistically significant effects on value added or labor productivity. Insignificant effects on value-added and productivity are driven by large firms

González and Pazó (2008)	Spanish data	1990-1999	Matching approach	Additionalities higher for SME and high-tech. Subsidies support SMEs, and low-tech firms to engage in R&D
Hall et al. (2009)	Italian data	1995-2003	Regression models	Subsidies enhances R&D efforts of SMEs
Czarnitzki and Lopes-Bento (2012)	Belgium, Germany, Luxembourg, Spain	2002-2004	Matching, and regression approach	Rejection of crowding-out. They analyse the counterfactual situation and find that In case of having received a subsidy, firms would have spent more in R&D.

Subsidies and high-tech versus low-tech funding

Czarnitzki and Delanote (2015)	German CIS and Patent data	1994-2006	Matching, Poisson models	Additionality more pronounced for young high-tech firms in terms of R&D investment and patents
Czarnitzki and Thorwarth (2012)	Belgium survey data	2002-2007	Regression models	Large effect of basic research for firms in high-tech industries, but no premium in low-tech sectors.

Size and form of grant

Görg and Strobl (2007)	Irish data	1998-2002	Matching, Difference-in-Difference	Additionality for domestic and small grants. Substitution for domestic and too large grants
Aschoff (2009)	German	1994-2005	Matching approach	Additionality. Frequently given grants as well as medium and large sized grants are effective to increase private R&D.

Funding source

Czarnitzki and Lopes-Bento (2014)	German CIS	1992-2006	Matching approach, Regression models	Co-existence of national and European policies does not cause crowding-out Grants from multiple sources lead to additionalities
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The components of R&D: R vs D funding

Clausen (2009)	Norway CIS	1998-2001	IV estimation	Public <i>Research</i> subsidies enhance private R&D, <i>Development</i> grants more likely to crowd-out private R&D
Hottenrott et al. (2015)	Belgium survey data	2000-2009	Matching approach	Presence of cross scheme effects: <i>Development</i> grants can also stimulate private R&D in research related activities

Subsidy versus tax incentives

Santamaría et al., 2010	Spanish data	2000-2003	Probit, and Tobit models	Tax credit schemes often chosen for projects to close-to-market. Subsidies often selected for projects with more basic character
Carboni (2011)	Italian data	2001-2003	Matching, and Regression models	Additionality. In the Italian sample, tax credits more effective than direct grants.

Tax incentives

First, we focus on the distribution of public funding with respect to tax credit schemes. Warda (2009) provides an overview of different tax schemes applied in OECD countries. Elschner et al. (2011) analyse the impact of various types of tax incentives as applied in the European Union on post-tax R&D expenditures of firms in different industries. Their study points out that the most important drivers of tax credits are the design of the incentive itself. This refers to questions such as should tax credits be applied on the entire amount of R&D expenditures (volume-based) or only on the increase of expenditures (incremental) and the overall consistency of the tax incentive scheme to the general tax system. The results indicate that for the evaluation of public support for R&D, it is often not sufficient to focus only on tax rate effects of R&D tax incentives. It also requires the accordance of the tax incentive scheme with the general framing tax system in order to be effective. The findings of their study further show the beneficial impact of immediate cash refunds for unused tax incentives.

Castellacci and Lie (2015b) present a meta-regression analysis (MRA) of micro-econometric studies on the effects of R&D tax credits on firms' innovation activities accounting for sectoral heterogeneity. The main finding of their MRA is indeed that sector affiliation matters.

They state that the additionality effect of R&D tax credits is on average stronger for SMEs, firms in the service sectors and firms in low-tech sectors in countries with an incremental scheme.

Finally, Lokshin and Mohnen (2012b) investigate the factors that influence the effectiveness of R&D tax incentives. They report that changing the value of the R&D tax parameters does not make a great difference in terms of net welfare gains and that volume-based tax credit schemes are less efficient than incremental tax credit schemes.

Direct subsidies

The study of the empirical literature on the relationship between public R&D subsidies and private R&D investment and innovation performance reveals a considerable heterogeneity of empirical results (see, for instance, the review by Zúñiga-Vicente et al. [2014]). To some extent, the heterogeneity can be explained by methodological issues; however, a more detailed perspective is needed on the distribution of public subsidies. This includes the amount and source of public subsidies (national versus international funding sources), the requirement to collaborate to receive public funding as well as if public funding has different effects if granted to small versus large firms and if the composition of firm R&D (research or development orientation) matters.

The impact of R&D collaboration

The requirement – or at least the encouragement – to collaborate with a firm or a university to receive public support has become an important policy feature of public support schemes. Previous literature show that R&D collaboration affects the type as well as the success of innovation projects. By the means of collaboration, firms can limit outgoing spillovers by internalizing them into the research consortium. Furthermore, collaboration enables firms to have access to complementary know-how, capabilities and resources of partnering firms. In sum, the literature emphasizes that R&D collaboration enhances private R&D activities substantially (Cassiman and Veugelers, 2002; D'Aspremont and Jacquemin, 1988; DeBondt, 1997; Kaiser, 2002; Kamien et al., 1992; Katz, 1986).

With respect to public support for collaborative R&D, subsidized collaborative R&D has received less attention in the empirical literature. Busom and Fernández-Ribas (2008) show that participation in R&D support generally increases the chances that firms engage in a collaboration with a public research institute or a private firm. Regarding the output additionalities of subsidized collaboration, Sakakibara (2001) and Branstetter and Sakakibara (2002) show that participating firms have higher R&D expenditures as well as more patents. Further, applying a matching approach in a treatment effect analysis, Czarnitzki et al. (2007) find that R&D collaboration has a positive effect on R&D per sales and patent outcomes in the case of public funding for Germany and Finland. Hottenrott and Lopes-Bento (2014) add another aspect to the current understanding of the effects of subsidized collaboration. Their paper questions whether the nationality of the collaboration partner matters. Hottenrott and Lopes-Bento (2014) find using a sample of Belgian firms that international collaborating firms have a higher subsidy treatment effect than nationally or non-collaborating firms. Furthermore, Beck et al. (2016) analyses whether different types of collaboration partner (i.e., horizontal, vertical or collaboration with science) within a subsidy scheme

can further enhance the effect created by the subsidy. Notably, they analyse the subsidy effects depending on different degrees of innovation novelty. Their study reveals that overall collaboration – measured as a dummy – does not impact the sales share of either incremental or radical innovation; however, in case of differentiating between different partner types, their analysis finds that parts of the investment driven by collaboration (horizontal and science) turn negative in the case of incremental innovation. They conclude that the policy effect is not further enhanced by a specific collaboration strategy, and an adjustment of the requirement to collaborate should be taken into account. For instance, it seems the case that collaboration requires additional coordination efforts for firms, with which not every firm is able to cope. Additional problems may arise due to appropriation problems of the intellectual property gathered from subsidized collaboration.

Small- and medium-sized enterprises

Another stream of empirical literature in the context of subsidized R&D projects focuses on the size of the firm. Over the last decades, many innovation agencies have initiated special innovation support schemes for small- and medium-sized enterprises (SME) [see also Fosse et al. (2014)]. Contributing to the current debate on the distribution of public funding, these studies investigate whether subsidies have different effects if they are granted to large versus small firms. The review by Becker (2015) underlines the current understanding in the literature and indicates that public subsidies are particularly effective in stimulating R&D of small firms. Usually, small firms are considered as financially more constrained than large firms. Lach (2002) produced a seminal paper in this field; the study applies a difference-in-difference estimation for a sample of Israeli manufacturing firms. This study reports that R&D subsidies granted to small firms have a significantly higher effect compared to large firms. Another interesting finding of this study is that subsidies may crowd-out private R&D investments for small firms in the short-run, but public support generates strong positive effects after the first year.

The positive effects of subsidies granted to SMEs is also documented by the study of Hottenrott and Lopes-Bento (2014). Applying a treatment effect analysis, their study reveals that public subsidies especially stimulate additionalities in terms of R&D spending and market novelty sales in internationally collaborating SMEs.

Kaiser and Kuhn (2012) also support these findings to some extent. Their paper studies the long-run effect of a public support scheme for research joint ventures (RJVs) between public research institutions and industry in Denmark. Applying a neighbour matching and conditional difference-in-difference estimation approach, they find that the insignificant effects for subsidized research consortia in Denmark in terms of value added and productivity are mainly driven by large firms. Considering that large firms are often over-represented in many support programs, they suggest rethinking public support policies that are often designed in favour to support large firms.

From a Danish perspective, DASTI (2015) analyses the effects of participation in EU framework programmes for research and innovation. Applying a nearest-neighbour matching and difference-in-differences estimations, this report finds that companies participating in the EU framework programmes FP6 and FP7 for research and innovation experience substantial effects, though these are not statistically significant when compared to similar non-participating companies.

Another interesting facet from a policy perspective is the question of whether public subsidies can help firms that have previously not been engaged in R&D and switch to being R&D-active firms. González and Pazó (2008) show that mainly small and low-tech firms might not have engaged in R&D activities in the absence of subsidies. These findings are also supported by the study of Hall et al. (2009) using a sample of Italian SMEs. The authors find that having received a subsidy stimulates the R&D efforts of SMEs. In a recent coun-

try comparison study by Czarnitzki and Lopes-Bento (2012) on a sample of firms from Belgium, Germany, Luxembourg and Spain, the authors find that an extension of the subsidy to firms which have not received a subsidy would cause those firms to generate significantly more R&D expenditures.

High-tech versus low-tech funding

Following the previous studies in this report, policy makers are also interested in whether they should support specific sectors. While there are some sector-specific studies such as Irwin and Klenow (1996), in our report, we focus on the distinction between high-tech versus low-tech sectors. Generally, consistent empirical evidence in this field is lacking. By pointing out some recent studies on this topic, we highlight some studies with contrary findings.

Czarnitzki and Delanote (2015) evaluate the effects of subsidies on input (R&D investment) and output additionalities (patent outcomes) and compare young high- and low-tech firms. They find that the additionality effects are particularly pronounced for young high-tech firms. Hence, they conclude that the current focus of EU policy makers on small- and medium-sized, young, independent firms in high-tech sectors seems to be “not ineffective”. This is in line with the findings of Czarnitzki and Thorwarth (2012), who, in their firm-level panel analysis based on Belgium firms, find an additional stimulus of basic research for firms in high-tech industries but no premium in low-tech sectors.

However, these findings are in contrast to other studies, such as González and Pazó (2008) and Becker and Hall (2013). The results of these studies indicate that firms in high-tech sectors may crowd out incremental public funding for firms’ internal investments.

Size and form of subsidy grants

Another important aspect for policy makers is the question of whether the amount and the form of the grant matters. Next to the amount of the grant, the form of

the subsidy can also matter. This refers to the scheme for how the grant is provided to the firm. Here, specific questions – for example, does the subsidy cover the salaries of the researchers, and does the firm need to self-finance other expenses – are of importance. These aspects on the form the grant are rarely covered in the empirical literature. Hence, in this subsection, we limit our focus to the size of the grant.

In the above mentioned studies, the amount of the subsidy granted to the firm has been ignored. Two reviews about the effects of public subsidies summarize some relevant studies that address this question (Becker, 2015; Zúñiga-Vicente et al., 2014). Both reviews underline the findings of Guellec and Van Pottelsberghe (2003), who find a non-linear relationship between the amount of governmental funding and input additionalities measured in terms of R&D investments. Hence, the relationship between government funding for corporate R&D and private R&D investments is positive and follows an inverted U-shape relationship with decreasing marginal effects. This indicates that above a certain threshold of the funding (estimated to be around 10 % of total Business R&D), the government supports crowding-out private investments. It is important to acknowledge that those estimations are based on the average governmental funding rate of the countries and do not account for the amount of the grant provided to individual R&D projects.

On the firm level, the above mentioned findings are supported by Görg and Strobl (2007) for Irish firms using a non-parametric matching procedure with difference-in-differences estimations. Their results indicate that for domestic plants, a grant on a small or medium level does not crowd out private R&D or even lead to additionalities. Large grants, however, in the case of Irish firms, may be used to cover R&D expenses for projects that would have been undertaken even in the absence of the subsidy (Görg and Strobl, 2007, p. 231). All findings yield substantial additionality.

Applying a matching approach on German CIS data from 1994 to 2005, Aschhoff (2009) finds that a minimum grant amount is necessary to stimulate crowding-in effects for R&D investments and that the generated subsidy effects depend on the size of the project. This study concludes that for a given subsidy amount, larger project sizes correspond to higher chances that the public will support additional crowd-in private investments. From a policy perspective, and taking into account that there are financial constraints for public R&D support, the non-linear relationship between subsidies and the generated additionalities lead to a trade-off between supporting a larger amount of projects at an intermediate level and providing larger amounts of money to some fewer larger projects. Overall, these findings indicate that it is not possible to draw strong conclusions about the relationship between the size of grants and the created additionality.

BOX 1.

Community Innovation Survey (CIS)

The Community Innovation Survey (CIS) is the most important source for research in innovation in Europe. It was first collected in 1992 and had follow-ups in 1996, 2001, 2006, 2008, 2010, 2012 and 2014. The 2016 wave is presently being collected. The survey instrument is harmonized across all participating countries, following the Oslo Manual (OECD, 1992).

The CIS asks firms from manufacturing and (from 2001) services questions regarding their innovation activities, R&D investments, sources for innovation, innovation success, factors impeding innova-

tion, etc. The questionnaires can be downloaded from <http://ec.europa.eu/eurostat/web/microdata/community-innovation-survey>. This website also contains an overview of which countries participated in what years.

The CIS is part of the EU science and technology statistics. As participation in CIS is voluntary, both for the interviewed firms and for the countries participating, not all countries took part in all surveys. Many countries such as Germany, the Netherlands or Belgium annually collect the data.

Funding source

In many countries, firms can apply for grants from different agencies. Those can be national or regional innovation agencies or even international ones, such as innovation support from the EU. The vast majority of empirical studies do not account for the difference in the origin of the subsidy and estimate an average effect of the subsidies or the effects of a specific subsidy scheme under consideration (Becker, 2015; Zúñiga-Vicente et al., 2014). One of the few exceptions in that field is the study by Czarnitzki and Lopes-Bento (2014). In their treatment effect analysis on the firm level, they analyse the different effect of European and national sources of public funding on innovation input (R&D investments) and output measures (patenting). With respect to innovation input, their study does not reveal that one policy substitutes the effect of the other. Finding positive output additionalities, the authors argue that receiving multiple grants from different sources complements each other and that the

co-existence of national and European policies does not cause crowding-out effects (Czarnitzki and Lopes-Bento, 2014, p. 380).

Given the lack of in-depth understanding about how project awarding criteria, requirements and application procedures vary across agencies, and given the heterogeneous empirical results of subsidy effects, more research would be needed to evaluate the interdependencies of different funding sources. Going in this direction, an earlier study on a sample of Spanish firms by Busom and Fernández-Ribas (2008) analyse the determinants of subsidy program participation using a sample of Spanish firms. Their results suggest that firms within the industry face different obstacles to participate in different agencies' programs, which causes potential selection issues. Additionally, they argue that program participation patterns may depend on a combination of agency goals and that these patterns differ across high-tech and low-tech industries (p. 1459).

The components of R&D: R vs. D funding

Following the previously mentioned distinction between different funding sources, further studies distinguish between the individual components of R&D in the context of public funding. This utilizes the notion that R&D as a whole does not constitute a homogenous activity, and one should at least treat its major components ‘Research’ and ‘Development’ as separate activities (Aerts and Thorwarth, 2008; Barge-Gil and López, 2015; Clausen, 2009; Czarnitzki et al., 2009). Clausen (2009) distinguishes between public research and development subsidies and analyses their effects on private R&D and other innovation outcomes on firm level using CIS data from Norway. He finds that public research subsidies stimulate private R&D investments, whereas development subsidies are more likely to crowd-out these investments. Hence, public subsidies seem to have stronger stimulation effects for projects where the gap between the social and private rate of return from R&D are larger (p. 251). From a policy perspective, this paper provides support that public support programs should be targeted more on projects that are novel and uncertain, which are hence considered more “far from the market” (p. 251). Similarly, analysing a policy support design in Belgium, Hottenrott et al. (2015) report positive effects from research and development subsidies on net research and development spending. Specifically, they show that the effect for research grants is larger than for development grants. Interestingly, their analysis reveals the presence of cross-scheme effects that may arise due to complementarity between research and development activities. Notably, their findings on cross-scheme effects of subsidies underline the view that public support can stimulate additional private R&D investment, particularly in research-related activities, and even in the case when the subsidies are designed to support development-oriented activities.

Subsidy versus tax incentive

Policy makers can use various policy instruments to stimulate R&D in the private sector. However, there is a lack of understanding on the effectiveness of differ-

ent policy instruments compared to each other. In this area, empirical evidence is quite scarce. The review by Becker (2015) presents some further studies that focus on different timing effects between direct subsidies and tax incentives. According to this review, there seems to be a consensus in the empirical literature that tax credits have a significant effect on private R&D investment mainly in a short time horizon, whereas subsidies have a positive effect in the medium to long run but less so in the short run. In summary, a tax credit incentive scheme is supposed to show quicker effects than that of a direct subsidy scheme (David et al., 2000; Guellec and Van Pottelsberghe, 2003). An explanation for these findings might be that projects relevant for tax reduction have already been planned or even chosen by the firm, hence enabling short-run effects. In contrast, projects applicable for a subsidy scheme might to a higher degree have a long-run perspective to be successful for subsidy approval.

There are some countries where both support policies – direct R&D subsidies and tax credits – are in place at the same time to address different objectives. Santamaría et al. (2010) analyses the decision making process of the agency to assign projects to specific policy instruments using a project level from Spain from 2000–2003. They find that projects that are close to the market are generally well supported through credits, while projects that are more basic receive rather selective support in the form of subsidies. In the analysis on Italian firm-level data, the non-parametric matching approach by Carboni (2011) suggests that Italian sample tax incentives are more effective than direct grants.

Overall, the literature in this field sheds light on potential substitution effects of tax credits and direct subsidy schemes. Hence, a policy mix composed of tax incentives and direct subsidies should be coordinated in an effective way to stimulate additional R&D investment. Further research on the evaluation of cross-scheme effects between subsidies and tax incentives and effective policy mixes would be highly appreciated.

Wrap-up

Both policy instruments are able to stimulate R&D in the private sector. In comparison to the public expenses for these policy measures, we can conclude that tax incentives and/or direct support help to correct market failure. Empirical studies suggest that tax incentive schemes are effective in the short-run and constitute effective means to increase R&D efforts in SMEs as well as low-tech sectors and countries with incremental incentive schemes. Notably, the tax incentive schemes need to be designed in accordance with the general tax scheme. Direct public R&D subsidies require a minimum amount of grant size and time in order to create additionalities. Empirical evidence shows that direct subsidies are especially effective to stimulate innovation in areas with higher degrees of innovation novelty. From a policy perspective, building on Guellec and Van Pottelsberghe (2003), we would like to draw some general policy recommendations. First, any type of policy instrument is more likely to show the desired effects if the policy is integrated in a long-term policy framework and is somehow stable over time. The positive effects might be related to the decrease in uncertainty for firms and hence may enable better strategic planning and coordination. Second, there should be consistency between the policy instruments with each other, which requires coordination and management between the agencies involved. Third, positive effects from public funding for R&D in the private sector require a certain amount of governmental support; hence, the subsidy should not be too low nor too high. Fourth, the policies instruments and schemes (e.g., awarding criteria, level of grants) should be designed in alignment with the national innovation system and the national or regional industry structure.

5. Public research, education and R&D labor market

1. Introduction
 2. Methodology
 3. The effects of private R&D on firm performance and economic growth
 4. Public funding of R&D investment
 5. **Public research, education and R&D labor market**
 6. What is the effect of knowledge transfer on firm performance or growth?
 7. Conclusion
- Literature

Chapters three and four have discussed the importance of research spillovers for innovation and innovation policy. This chapter deals with the two important drivers of industrial innovation: basic research (Chapter 5.1) and labor mobility (Chapter 5.2). Both mechanisms are, of course, related, since the mobility of labor is an important source of knowledge spillovers. Since there are, however, many other mechanisms through which knowledge disseminates from university to industry, and since the literature on labor mobility and innovation is quite rich, we treat both separately in this review.

The literature on the link between university and industry – be it with regard to knowledge flows as in Subchapter 5.1 or with respect to labor mobility as discussed in Subchapter 5.2 – is to a large extent based on patent counts as they constitute validated proxies for innovative activity (Archibugi, 1992; Basberg, 1987; Griliches, 1990; Scherer, 1982; Schmookler, 1966). Similarly, patent citations data are validated proxies for knowledge flows (Hall et al., 2000, 2001; Jaffe et al., 2000; Trajtenberg, 1990) – even though recent evidence by Roach and Cohen (2012) has shown that patent citations most closely represent codified knowledge, which implies that they may not proxy well public-private knowledge transfers that are often more contract based.

5.1 HOW IMPORTANT IS INVESTMENT IN PUBLIC RESEARCH AND EDUCATION?

I think it is obvious that the central mission of universities should be the traditional one of the advance and spread of knowledge (...).
(Nelson, 2006, p. 916)

In their review of the benefits of public research for industry, Martin et al. (1996) as well as Salter and Martin (2001, p. 520) list six main ways through which “research based educations” may impact the corporate world and society at large: (1) increased stock of “use-

ful” (i.e., commercializable) knowledge, (2) trained graduates, (3) creation of new scientific tools and methods, (4) formation of networks and technologically stimulating social interaction, (5) increased capacity for technological and scientific problem solving and (6) creation of new firms. Salter and Martin (2001) provide an extant review of the literature on each of these topics.

While we agree that the list by Salter and Martin (2001) is useful, we find some of the items to be hard to distinguish, e.g., items (1), (3) and (5). In addition, there is not much new empirical evidence on items (3) and (5). Item (4) appears to be closely related to our Subchapter 5.2 on labor mobility to which we also relegate the discussion. We hereafter discuss the three main areas – “*useful*” *knowledge creation, training of graduates and the creation of new firms* – and the latter is described in detail in chapter six. We add an additional layer, the internationalization of science, to account for the huge increase in globalization in research in the past two decades. Levy et al. (2009) as well as Owen-Smith et al. (2002) provide alternative typologies of different types of knowledge transfer mechanisms between university and industry. We review those in Chapter 6. Martin and Tang (2007) characterize how basic research may affect productivity and growth.

“Useful” knowledge creation

Ever since the research of Schumpeter (1934), economists have recognized that R&D is a pronounced driver of growth and that basic, university-based knowledge may play a particularly important role innovation and productivity (Dasgupta and David, 1994; Dorfman, 1983). The review by Frontier Economics (2014) provides a comprehensive review of the economic growth-related aspects of innovation and R&D, while we cover micro-level evidence only.

The early work of Nelson (1959) already discusses important economic aspects of basic research conducted at research universities. His main concern deals with the incentives to conduct basic research,

and he suggests that they do not lead to a temporary monopoly as applied research does when it's underlying invention is granted a patent. He cites case-study evidence for the link between basic science and commercialized innovation to point out that the private sector should have incentives to subsidize public research (and to recognize that they all have incentives to gain a 'free ride' from each other's efforts). In a follow-up paper, Nelson (2006) criticizes recent policy efforts to move universities closer to industry, since this may undermine the long-run positive effects of public R&D on industrial innovation; this is a view also shared in review articles by Pavitt (1991) and Rosenberg (1990).

Rosenberg (1992) traces the link between university research and the generation of new scientific instruments since World War II, finding evidence for a causal relationship that runs from public research to the corporate world. Nelson (1996) uses information on the type of technology that is licensed out at Columbia University to show that instruments and methods are the dominant technologies that are adopted by private sector firms. Supporting evidence comes from Arundel et al.'s (1995) survey data, which show that large European firms find "specialized knowledge" to be the most important output by universities.

Survey-based evidence on the usefulness of academic research on industrial innovation is provided by Mansfield (1991, 1995). He uses survey data on 66 firms in US manufacturing industries (combined with information on around 200 academic researchers for his 1995 paper) to show that the surveyed firms indeed report that academic research has been key to their innovative activities. This importance is, however, restricted to only a few sectors: pharmaceuticals, electronics, information processing, chemicals, and petroleum. He also shows a weak link between faculty reputation and university contribution to industry. Regarding geographic proximity of universities, Mansfield (1995) shows that closeness only matters for applied research. Mansfield (1991) also provides estimates for the social

return from science, which he assesses to be in the range of between 20 and 30 percent.

Arvanitis et al. (2008a) as well as Beise and Stahl (1999) adopt a similar methodology as Mansfield (1995). Using survey data from Switzerland, Arvanitis et al. (2008) consider various types of knowledge transfer activities between universities and industry in Switzerland – "general information", education, research and technical infrastructure and consulting – to show that all significantly contribute a wide range of innovative outcomes. This broad finding is similar to analysis for Germany by Beise and Stahl (1999), whose study touches upon an important aspect relevant for many European countries: the role of federal research laboratories like the Max Planck Institution, the Fraunhofer institution in Germany or that of the "Godkendte Teknologiske Serviceinstitutter" in Denmark. Beise and Stahl's (1999) survey data show that their role for commercialized innovation is very limited. They also find little evidence for the importance of geographic proximity. Using UK survey data matches with CIS data, Bishop et al. (2011) show that while all of the seven university-industry technology transfer mechanisms appear to benefit corporate innovation, geographic proximity and university quality does matter for corporate performance. Similar evidence is provided by Howells et al. (2012), who use UK survey data and who generally find a positive link between various types of university-industry collaborations.

In a comprehensive study that links around 15000 universities in about 1,500 regions in 78 countries and that goes back to the 11th century, Valero and van Reenen (2016) find strong positive impact of the presence of universities on regional growth and firm performance. They identify the supply of skilled workers as a main contributor of both economic growth and innovation performance as measured by patent counts.

Whatever the deeper reasons for the feedback from university to industry are, knowledge spillovers appear to exist. The very influential study by Jaffe (1989) assesses

the magnitude of knowledge spillovers using US state-level panel data. He estimates knowledge production functions that consider both spillovers from the private sector and spillovers from universities. His spillover pools are constructed using the technological distance measure introduced in Jaffe (1988). His key finding is that there exists evidence for both public and private spillover effects on corporate patenting and that public spillovers are particularly important in Drugs, Electronics and Nuclear Technology. Jaffe (1989) also provides

weak evidence for a causal link that runs from university spillovers to private sector R&D. Using similar empirical approaches and the NBER patent data, Henderson et al. (1998) as well as Jaffe and Trajtenberg (McMillan et al., 2000) show that university patents receive more citations than corporate patents and that they are more generally applicable. These positive effects of university research occur despite that university research is “fundamental” (Rosenberg and Nelson, 1994).

BOX 2.

The NBER patent data

The NBER dataset arguably is the most important source of information for scholars interested in the Economics of Innovation. It consists of (i) all patents applied for at the USPTO between 1976 and 2006, (ii) the corresponding patent citations and (iii) firm-level financial information on the patent assignees.

The methodology behind the NBER patent data is described in detail by Jaffe and Trajtenberg (2002) as well as Hall et al. (2001). Additional documentation as well as the data set are to be found at <http://www.nber.org/patents/>.

Related work by Zucker et al. (1994) for US biotechnology find strong evidence for the importance of university research for private sector R&D; this result is shared by McMillan et al. (2000), who use the proprietary patent citations data owned by Computer Horizons Inc. (CHI). In more recent work, Belenzon and Schankerman (2012) study the link between geographic proximity and citations to university patents and scientific publications using data on 184 US research universities. They show that the likelihood of citing a university patent strongly declines with distance and that the likelihood of citing a university patent from an out-of-state university is substantially smaller than the probability of citing

an in-state patent. The latter effect is, however, moderated by university quality – it is stronger for lower quality in-state universities. Related evidence for localized university spillovers comes from Mowery and Ziedonis (2015) using US patent citations data.

Henderson et al. (1998) evaluate how “useful” university research is for private R&D. Their main conclusion is that until the mid-1980s, university patents were more highly cited and cited by more diverse patents than a sample of control group patents taken out by private sector firms. The importance of university patents has, as they show using the NBER patent data, declined

since then, despite the “explosion” in the number of university patents; this effect might be traced back to the Bayh-Dole act of 1980 and its expansion in 1984. The decline in the importance of university patents coupled with the increase in university patents might of course simply reflect that the Bayh-Dole act brought about many unimportant university innovations, as pointed out by Mowery et al. (2001) and Mowery and Sampat (2005).

In work also based on the CHI data, Narin and Olivastro (1992) show that the connection between science and industry is by and large only important in pharmaceuticals, chemicals and electronics, thereby echoing Jaffe’s (1988) earlier finding. In a follow-up paper, Narin et al. (1997) use data on the citation of industrial patents to “non-patent references”, which they argue are likely to be related to university research. They document an upward trend in citations of US patents to these non-patent references and hence an increasing importance of university research for industry. In a study for 79 Flemish firms and their granted patents, Cassiman et al. (2008) find that patents with non-patent references do receive the same number of forward citations as other patents. However, these patents are more likely to be cited in a foreign patent and to be cited by patents from other technology field – they hence are more general. While most existing work study the effects of science on industry, Arora et al. (2015) take a reverse perspective by studying the patenting and publication patterns of US corporate scientists over two decades. They show that their contribution to scientific research has decreased but that their contribution to technical knowledge has increased over time.

Meyer (2000) questions this claim by conducting a case study in the nanoscale technology industry. He closely examines the front pages of ten patents to infer how much science these patents actually contain, finding that there is no evidence for a direct relationship between patents that cite university research and university research itself.

Caballero and Jaffe (1993a) add a macroeconomic perspective to the discussion by first deriving a macroeconomic model, which is a neo-Schumpeterian theory of economic growth that pins down the link between public research, spillover, corporate R&D and social welfare. Using the NBER patent data set, they show that their empirical results are broadly consistent with their theoretical model. An important empirical finding in the present context is that the rate of “usefulness” of public research has steadily declined and that knowledge rapidly diffuses.

European evidence on university-private sector knowledge flows is provided by Bacchiocchi and Montobbio (2010), who use EPO patent application and citations data for France, Germany, Italy, the UK and the US. They first derive a theoretical model similar to Caballero and Jaffe (1993) and, like them, estimate it in a semi-structural way. Their results show that university patents are more likely to be cited than corporate patents but that this effect is again primarily driven by chemicals, drugs and mechanics as well as US universities. Maietta (2015) uses data on a low-tech industry: Italian food processing. Even in that low skill, low-tech sector, she finds significantly positive effects of university-industry collaboration on both product and process innovation. Following Narin et al.’s (1997) non-patent citations’ definition of industry-science links, Cassiman et al. (2008) show that citations to non-patent sources do not lead to more forward citations but that patents with such citations are more widely applicable. Czarnitzki et al. (2011b) come to somewhat different conclusions for forward citations of industry patents. Their study is based on a large number of German European Patent Office patents taken out by applicants with a “Professor Dr.” title between 1978 and 2006 and finds that corporate patents that have a science link receive a forward citation premium.

Toole (2007) uses data on the US biotechnology industry to show that public research is positively correlated with private R&D investments but that this correlation

occurs with a lag. Following up on his earlier research, Toole (2012) documents an economically and statistically significant positive correlation between scientific publications and the number of new molecules in US biotechnology. Evidence in favor of complementarity between public and private R&D is provided by Veugelers and Cassiman (2005), who use Belgian CIS data and who account for the potential simultaneity of innovation strategy choices. They also show that large firms and firms in chemicals and pharmaceuticals are most likely to have links to university research.

Somewhat conflicting evidence comes from Quaglione et al. (2015) as well as Muscio et al. (2013), who use data on the population of Italian university departments between 2006 and 2011 to show that there exists some evidence for substitutive effects between public and corporate R&D in life sciences and less so for engineering and technology departments. There is, however, evidence for complementarity for departments that focus on basic sciences. Two cross-country panel data studies that both include Denmark – Guellec and Van Pottelsberghe (2003) and Falk (2006) – try to directly estimate the relation between research conducted at universities and private R&D efforts. Guellec and Van Pottelsberghe (2003) use a panel dataset of 17 OECD countries that covers the years 1981 to 1996. They estimate dynamic panel data models and do not find significant effects of research conducted by universities on private sector R&D spending. Falk (2006) reviews existing studies on the link between public and private sector R&D and estimates systems of simultaneous equations using GMM on a panel of OECD countries observed between 1975 and 2002. He finds that research activities carried out by the public sector lead to an increase in private R&D spending. He estimates the corresponding elasticity to be one – a one percent increase in public R&D is associated with a one percent increase in private R&D expenditures.

Narin et al. (1997) link the strong growth of corporate patenting in the period 1987-1994 to the even stronger growth of university, or more generally, public research institution patenting and publishing. They argue that public sector research complements rather than substitutes private sector research; this view is shared by Meyer-Krahmer and Schmoch (1998). Klevorick et al. (1995) as well as Nelson (1986) explain this phenomenon by basic research generated by universities that expands the technology space of industry, while Mowery (1995) concludes that university research enhances the efficiency of corporate research. Steinmueller (1994) explains the complementarity by basic research reducing the option value of contemporary private research projects. Yet, the broadly accepted explanation for the complementarity of public and private research is, however, absorptive capacity: firms need to invest in R&D in order to be able to understand (to “absorb”) the research conducted by universities (Nightingale, 1997; Pavitt, 1998) and other firms (Cohen and Levinthal, 1989, 1990; Zahra and George, 2002).

Levin et al. (1987) report the key results of their survey – the so-called “Yale” survey – of 130 R&D executives. The survey contained questions of the sources of knowledge for innovation. Linking this variable to R&D intensity and innovation, they show that they are positively related to one another. In follow-up work, Nelson (1986) provides further evidence for a positive correlation between university research and private sector R&D intensity and argues that university research expands technological opportunities rather than generating commercializable innovations itself.

BOX 3.

Yale survey

The “Yale innovation survey” from 1987 and successor, or second wave, from 1994 is often referred to as the “Carnegie Mellon Survey” (or “Yale II survey”) and originates from an initiative of Richard Levin, Alvin Klevorick, Richard Nelson and Sidney Winter. The 1994 survey was administered by Carnegie Mellon University under the supervision of Wesley Cohen.

Both surveys collected information from R&D directors of US manufacturing firms, and the surveys contain information on the determinants and outcomes of their R&D activity. It also contains information on how the R&D directors perceive the

effectiveness of alternative means to protect one’s own R&D efforts, where they gather innovation input from, how they interact with upstream and downstream firms as well as universities and how fast their own technologies diffuse.

The Carnegie Mellon survey questionnaire was already designed to generalize to other countries and other industries. Surveys similar to Yale II have been and still are conducted in Canada, Japan, and perhaps most importantly in many European countries as the “Community Innovation Survey” (CIS) that is described on page 30.

In a follow-up paper, Cohen et al. (2002) use Yale survey data to underscore the importance of public research on corporate research. Moreover, they find that public R&D is not only positively linked to the generation of new ideas but is also positively associated with the completion of R&D projects and that it leads to starting new research projects. Studying the sources of these effects, they find that the means through which knowledge is transferred from university to industry are academic papers, conferences, informal information exchange and consulting. Finally, Cohen et al. (2002) show that university knowledge is more important for larger firms than for both smaller firms and for startups compared to established firms.

In a sociological study of US and UK corporate scientists, Faulkner et al. (1995; 1994) underscore the importance of personal links between private and

public sector scientists. Similarly, Rapp and Debackere (1992) use international survey data on 700 scientists and engineers to show that private sector researchers recognizes public sector researchers as an important knowledge repository despite the latter’s tendency to publish their inventions rather than to create patents. The importance of the building of scientists’ networks is also underscored by Callon (1994) in his review of anthropological and sociological studies. Also, Foray and Lissoni (2010) review the older literature on scientists’ personal links between the public and the private sector.

Danish evidence on the importance of informal university-industry networks and of geographic proximity is provided by Østergaard (2007). He uses survey data of engineers and computer scientists in the wireless communication cluster in Northern Jutland. The data

show that scientists who had previously been involved in a formal industry-university collaboration or who had studied at the local university were more likely to report that they acquired knowledge from university scientists.

Using survey data from large European firms from 16 different industries across European countries – the so-called PACE survey, a predecessor of the Yale survey – Arundel et al. (1995) show how the link between public and private R&D may come about. They show that the most important source of learning from public research is publications followed by informal contacts as well as – with some distance – hiring, conferences and joint research. In subsequent work, Arundel and Geuna (2004) review the results of their PACE survey, the CIS data from 1997 and the Yale survey and argue that the importance of geographic distance between a potential public research knowledge base increases with the quality of the public research institution. This result is shared by Abramovsky and Simpson (2011), who use British firm-level register data and count data models, as well as by Laursen et al. (2011), who use UK survey data.

Finally, the perhaps second most direct form after the production of scientists of public-private knowledge transfer are public-private research collaborations. Cockburn and Henderson (1998) use a sample of ten pharmaceutical firms to show that research collaborations between public and private sector employees increases the quality of the joint patents as measured by patent citations, which they interpret as a substantial social return to public investments in public research; this key finding is shared by Gittelman and Kogut (2003) for 116 the US biotechnology firms. While Zucker et al. (1997) underscore the positive effect of university “star scientists” who entertain that some links to industry are particularly important for corporate innovation in US biotechnology, Rothaermel and Hess (2007) show that non-star scientists are of even higher importance.

Training of graduates

While it is clear that there exist important knowledge flows between university and industry, the most direct transmission channel – the training of future workers – is not well investigated. To study the impact of workers who leave a university after a post-graduate stay to join the private sector, Kaiser et al. (2016) combine Danish patent data with assignee (firm-level) data and link these to employee-level data. This enables them to track R&D workers and their employers. Their data contains 16531 observations on 5714 unique firms over the period 2000 to 2004. Kaiser et al. (2016) use dynamic count data models that account for the potential endogeneity of firms’ hiring decisions and for firm fixed effects and find that incoming university joiners have a substantial positive effect on their employers patenting activity. More generally, they find any previous exposure to the university research environment leads to statistically and economically significantly larger effects on corporate patenting than joiners from the corporate world without any prior university research experience. This effect is attenuated if the top management team comprises of at least one R&D worker and if the hiring firm is a patent-active firm. Kaiser et al. (2016) finally also show that recent graduates also contribute statistically and economically significantly to the patenting of their new employer.

Other more recent related work includes the papers by Cowan and Zinovyeva (2013), Leten et al. (2014) and Rothaermel and Ku (2008). Leten et al. (2014) estimate regional production functions using Italian panel data on 101 Italian provinces and four industries – chemicals, pharmaceuticals, electrical engineering and mechanical engineering – between 1992 and 1998. They find evidence for a positive association between the technological performance of firms and both the number of university graduates and the number of scientific publications within a region. More Italian evidence is provided by Cowan and Zinovyeva (2013) who show that the establishment of new universities and colleges in Italy has led to an increase in regional innovation

activity and that this effect that is particularly strong for less developed regions. In their study on the US medical device industry, Rothaermel and Ku (2008) identify a “critical role” of universities as a source of regional knowledge spillovers. They also stress the importance of university graduates as a driver of knowledge transfer.

The older empirical literature starts with Gibbons and Johnston (1974), who study 30 UK private sector innovations and find evidence for public research having benefited these innovations; they speculate that the training of students by the public sector might have, in particular, helped the creation of these innovations. Similarly, Martin and Irvine (1981) conduct a case study in the UK radioastronomy industry to show that innovation in that sector is primarily driven by educated scientists (“manpower effects”) and academic spin-offs. In more narrative work, Nelson (1987) emphasizes the importance of science teaching that endows graduates with the relevant scientific know-how without requiring them to do any academic research themselves; this view is shared by Senker (1995), who emphasizes the importance of a new scientist to absorb new technological knowledge.

Klevorick et al. (1995) use the results of the Yale survey to show that one of the main mechanisms through which university knowledge disseminates to industry is the training of industrial scientists and engineers by universities. The other main route is through basic science and its effect on applied industrial research. Using the Yale survey data again, Rosenberg and Nelson (1994) show that the little role that fundamental science plays in the importance for corporate innovation may ignore the long-term effects of basic research on corporate research. The long-run effects of science is also emphasized in Adams (1990) seminal study on the effects of “fundamental” stocks of knowledge that shows that the stock of scientific papers has an economically and statistically significant effect on economic growth and that these effects occur with lags of up to 20 years.

Danish evidence on the mapping of university graduates and innovation is provided by Junge et al. (2015), who use survey data matched with register data to show that a higher share of tertiary educated workers leads to a higher likelihood of product, process and marketing innovations. They estimate growth models that account for potential endogeneity of firms’ employment choice. Two other studies of Denmark – those by Parrotta et al. (2014) and Østergaard et al. (2011) – show that diversity in education is positively linked to firm-level innovation. However, neither study is able to separately analyze the impact of mobile workers from universities.

International scientist mobility

Our final perspective on the importance of research-based education (and mobility, covered in the next subchapter) is an international one. An interesting and highly relevant literature for contemporary policy making on international scientist mobility has emerged in the past decade that studies the contribution of migrant scientists to domestic innovation.

Our point of departure is an extensive review of the literature on the “brain drain” by Docquier and Rapoport (2012), who show that high-skilled migration today constitutes the most important type of labor mobility across countries. It is not only that high skilled labor moves in increasingly high numbers. It is also that these mobile workers often outperform comparable domestic workers, even when self-selection is incorporated into migration. Freeman (2013) even argues that international migration is the key factor for knowledge flows between developed and developing countries; that is, it is the “one ring” that drives other aspects of globalization, like trade, capital flows and immigration. Nathan (2014) provides a survey of the literature on the effects of migration on innovation, productivity, trade and entrepreneurship, finding strong evidence for positive effects of skilled migration on all of his four outcome variables.

The productivity edge of migrant scientists is in the focus of a series of papers by Stephan, Franzoni and Scellato, who assembled unique survey data on the 16 core countries that onboard migrants in four scientific fields including Denmark as well as 14299 unique authors of scientific papers; this survey is known as the “GlobSci” survey. Based on this data, Franzoni et al. (2014) find strong evidence that migrant scientists outperform domestic scientists in terms of publication impact factors. Recognizing potential positive selection into mobility – the smartest university educated individuals might be the ones who move – they instrument current mobility by local and international mobility in the mobile scientists’ childhood. In a more detailed analysis, Franzoni et al. (2014) substantiate the previous evidence by comparing the scientific performance of return migrants to the performance of compatriot workers who never left their destination country. They find that there is no productivity difference between the two groups. In Franzoni et al. (2012), the authors study the determinants of emigration and return and find that career opportunities lure scientists away from their home country and that family reasons make them return.

Stephan et al. (2013) ask what factors determine a migrants’ choice to settle in the US. Key determinants are the quality of the program and career opportunities, while the US lifestyle has reverse effects. The attractiveness of US universities for training has decreased lately. Australia, Germany and Switzerland are benefiting from that trend, both for PhD and post-doctoral students, while France and Great Britain are attracting post-docs. Denmark neither gained nor lost from the relative increase in the inflow of foreign students into Europe.

While the stack of papers by Stephan, Franzoni and Scellato is based on self-reported survey data, Stuen et al. (2012) use information on the scientific productivity of migrants compared to domestic peers. They trace students enrolled at 2300 US science and engineering

departments over the period 1973-1998. They use the number of publications and the number of citations per publications as output indicators and show that migrant students are as productive as domestic students. Their study uses variation in the macroeconomic environment as well as changes in US visa policy and China’s science policy as instruments for labor mobility. Similarly, Stephan and Levin (2001) study the authors of the 250 most cited papers in the National Academy of Sciences and Engineering and show that foreign educated scientists are disproportionately often among the group of these star scientists.

The massive increase in the number of Chinese students who seek to attain a degree from a US university has recently become the subject of empirical investigations. Gaulé and Piacentini (2012) trace their productivity, as measured by the number of published scientific papers. They use data on 16000 graduates from 161 US chemistry departments to show that their output is significantly larger than that of the US peers, both in terms of first-authored publications and in terms of overall publications. They also perform similarly well in terms of receiving NSF grants. Gibson and McKenzie (2014) provide survey data evidence on mobility patterns and mobility outcomes for islands situated in the Pacific Ocean. Using propensity score matching to mitigate the problem of non-random selection into migration, they find evidence for migrants not only producing more research as measured by the number of journal publications and paper citations but that they also generate more research than migrants who returned to their home country after a period abroad.

While the aforementioned studies are all concerned with scientific publications, Hunt and Gauthier-Loiselle (2010) establish a link between foreign student intake and innovation as measured by patent counts. Using US state-level data that covers the period 1950-2000, they show that an increase in the share of foreign students in the total number of college-educated leads to an increase in patenting; this finding is robust to

the potential endogeneity of the migration decision. Similarly, Hunt (2011), using data from the US National Survey of College Graduates from 2003, finds that immigrants have a larger propensity to patent and to start a new firm than their domestic peers. The latter finding is shared by Wadhwa et al. (2008), who also find a strong correlation between having a tertiary education and starting one's own business, using US survey data.

These differences in patent productivity, as Hunt (2011) points out, are, however, primarily driven by differences in the choice of study subject and length of education. In two papers that use variations in US visa policies as instruments for mobility, Kerr and coauthors show that immigrants do at least as well as native scientists in terms of patent quality; this finding is robust to alternative definitions of patent quality (Kerr, 2013; Kerr and Lincoln, 2010). Chellaraj et al. (2008) combine various regional-level panel datasets and show that the number of foreign graduate students is positively related to both corporate and university patenting. Kerr (2008) shows that knowledge flows, as measured by patent citations from the US to other countries, are accelerated through migrant scientist clusters.

European evidence on the link between skilled migration and innovation is provided by Gagliardi (2014), who uses the British CIS data matched with register data. She uses historical shares of immigrants as an instrument for mobility and that foreign born scientists have a statistically and economically significant impact on corporate innovation. More European evidence comes from Bosetti et al. (2015), who use patent data and information on scientific publishing for a panel of 20 European countries including Denmark. They show that a larger number of foreign scientists are associated with both a higher number of patents and a higher number of patent citations; this finding is robust to using pre-sample migrant shares as instruments. Somewhat conflicting evidence for the benefits associated with foreign scientists does, however, come from Ozgen et al. (2013), who combine Dutch CIS and register data to

show that immigrants to the Netherlands are consistently less innovative than their domestic peers; this effect fades out for second-generation immigrants and is less strong in firms that employ larger shares of highly skilled employees. Ozgen et al. (2013) also apply IV regressions and use historical shares of immigrants as instruments but do not separate scientists from other workers, which might induce a self-selection problem.

That knowledge flows can be bi-directional is shown by a combination of case studies and patent citation data by Song et al. (2003). They show that there are close links between Korean scientists who previously worked in the US and who return to their home country and the propensity that the patents taken out by the new Korean employer cites a patent by the previous US employer.

Wrap-up

There is vast empirical evidence that universities and other public research institutions have a significant economic impact on industrial research, both directly through knowledge transfer and indirectly through the education of scientists. Geographic proximity to universities still appears to play a positive and important role. Proximity does, however, matter most for industry-university linkage of second-tier universities, while there are no such effects for top universities. Digitization may make geographic proximity less important, but social interaction is likely to remain important for knowledge transfer, as a Danish case study showed (Østergaard, 2007), in particular, if industry is not looking for a solution to a specific problem but rather for unspecific inspiration.

This existing evidence is predominantly based on patent citation data and survey data, and this evidence shows that public research crowds in rather than crowds out private R&D. More recently, scholars have begun to use register data coupled with patent and patent citation data as well as surveys, which allow scholars to track the entire working history of individuals. The

transfer of public science knowledge to industry is best investigated and documented for a few high technology sectors like pharmaceuticals and electronics. Much less is known, however, about the extent to which knowledge spillovers matter for low-tech industries. In addition, existing research has predominantly studied knowledge flows from university to industry, thereby ignoring possible reverse relationships.

The literature has hitherto not made an attempt to measure the importance of research content in an education or made differences in terms of length of education. It primarily either uses citations to university patents or links mobile individuals with a certain type of education or a particular academic degree to innovative outcomes.

The training of qualified research workers constitutes a second mechanism through which university affects industry. These movements constitute an important mechanism through which academic knowledge disseminates. Yet another mechanism of knowledge transfer to industry is the startup activity of graduates and post-graduates. The evidence on their importance to date is scant, which is in contrast to the research literature on direct university spinoffs. Existing research does, however, show that the number of startups founded by (post-) graduates is rising and that these startups do at least as well as other startups.

A key problem with the literature reviewed above is that causal effects are inherently hard to identify. The sorting and matching of workers is non-random, knowledge flows between university and industry may be bi-directional and international mobility is characterized by self-selection. Quasi-experiments that have a long tradition in labor economics of the type shown by Alslev Christensen et al. (Alslev Christensen et al., 2016) would constitute an important step towards a more proper assessment of university-industry interactions.

TABLE 7.*Results overview*

Study	Data	Period	Method	Main finding
“Useful” knowledge creation				
Rosenberg (1992)	Case study of US new scientific instruments sector	WWII-end of 90s	Qualitative study	“Causal” effects from public research to industry
Nelson (1996)	Technologies licensed out at Columbia U		Qualitative study	Instruments and methods dominant type of research absorbed by industry
Arundel et al. (1995)	EU firm-level survey data	1991 and 1992	Descriptive statistics	“Specialized output” rated most important by firms
Mansfield (1991, 1995)	66/76 US manufacturing firms	1985	OLS	Academic research key to industry innovation; relevant for a few high-tech sectors only; social rate of return 20-30 percent
Beise and Stahl (1999)	2300 firms; CIS Germany; cross-section	1995	Probits	Various types of knowledge transfer between university and industry is relevant to industrial innovation
Arvanitis et al. (2008a)	2582 firms CIS Switzerland; cross-section	2005	Probit, Tobit; IV	Same as Beise and Stahl (1999)
Bishop et al.(2011)	475 UK firms; survey data	1999-2003	Probit	Same as Beise and Stahl (1999)
Howells et al. (2012)	317 UK firms; survey data	2008/2009	Logistic regressions	Same as Beise and Stahl (1999)
Jaffe (1989)	232 obs.; NBER patent data	1972-1981	OLS IV	Significant spillover effects from academe to industry; most importantly for high-tech industries; evidence for causal effects of public research
Jaffe and Trajtenberg (1996)	NBER patent data	1963-1993	OLS	University patents receive more citations than corporate patents and have broader applicability
Henderson et al. (1998)	NBER patent data	1965-1988	OLS	Same as Jaffe and Trajtenberg (1996)

Zucker et al. (1997)	751 US biotechnology firms	1976-1989	OLS	Strong importance of university R&D for corporate R&D
McMillan et al. (2000)	2334 US biotechnology patents	1993-unclear	OLS	Strong importance of university R&D for corporate R&D as evidenced by patent citations
Belenzon and Schankerman (2012)	184 US research universities; 26914 granted patents	1975-2006	Probit	Likelihood of citing a university patent depends on distance and university quality
Mowery and Ziedonis (2015)	Patent and licensing record of three US research universities	1975-1988	Probit	Likelihood of citing a university patent depends on geographic distance
Henderson et al. (1998)	NBER patent data	1965-1988	Descriptive	Until Bayh-Dole university patents more highly cited and broader
Narin and Olivastro (1992)	Patent citations data	1975-1980	Descriptive	University-industry link relevant in high-tech only
Narin et al. (1997)	Patent citations data	1975-1991	Descriptive	Upward trend in cites to university patents by industry
Meyer (2000)	Case study nanos-clae industry	---	Descriptive	No evidence for direct university-industry relationship
Caballero and Jaffe (1993)	567 large US firms; NBER patent data	1965-1981	Structural estimation	"Usefulness" of academic patents has steadily declined
Bacchiocchi and Montobbio (2010)	EPO data	1978-1998	Structural estimation	University patents more often cited than corporate patents but effect driven by high-tech
Maietta (2015)	1744 firms from Italian food processing industry; survey data	1995-2006	Multivariate probit	Positive link between university and industry for product and process innovation
Cassiman et al. (2008)	79 Flemish firms and their patents	1995-2001	Count data models	University-science links do not affect citations but the number of patents
Czarnitzki et al. (2011)	4973 German Patent Office patents	1978-2006	Count data models	More citations to patents with science link than without science link
Toole (2007)	US drug industry	1981-1997	OLS	Positive effect of public R&D on private R&D but with a lag
Toole (2012)	US drug industry	1980-1997	Count data models	Positive relationship between scientific publications and new pharmaceutical molecules
Quaglione et al. (2014); Muscio et al. (2013)	Italian university departments	2006-2011	Tobit	Substitution between public and private R&D in life sciences but not in engineering and technology
Guellec and Van Pottelsberghe (2003)	OECD cross-country panel	1981-1996	Dynamic panel data	No significant effect of university R&D spending on corporate spending

Falk (2006)	OECD cross-country panel	1975-2002	GMM	Public sector R&D increases private sector R&D; the elasticity is unity
Levin et al. (1985)	Yale survey	1984	OLS	Many different information sources matter for corporate innovation
Nelson (1986)	Yale survey	1984	OLS	University research expands technological opportunities
Cohen et al. (2002)	Yale survey	1994	OLS	Public R&D complements private R&D and leads to a higher likelihood of project completion; universities are more important for startups and large firms
Arundel et al. (1995)	PACE survey	1992 and 1992	OLS	Underscores the importance of personal contacts between public and private sector scientists
Østergaard (2009)	Case study on wireless communication cluster in Northern Jutland (DK)	2005	Logistic regression	Previous contact to university increases likelihood of using university as knowledge source
Abramovsky and Simpson (2011); Laursen et al. (2010)	2318 postcodes; aggregated British register data	2003-2003	Count data	Distance and quality of university matters for university-industry relationship
Cockburn and Henderson (1998)	Ten US pharmaceuticals	1980-1994	Multinomial logit	Quality of corporate patents increases if universities are involved
Gittelman and Kogut (2013)	116 US pharmaceuticals	1982-1997	Count data models	Quality of corporate patents increases if universities are involved
Zucker et al. (2002)	US biotechnology star scientists; 3152 observations	90s	Count data models	Importance of star scientists with links to industry
Rothaermel and Hess (2007)	US biotechnology firms; 1782 observations	1980-2001	Count data models	Non-stars are even more important for public-private knowledge transfer
Training of graduates				
Junge et al. (2011)	Danish register data combined with CIS data		IV growth models	Higher share of tertiary educated leads to higher probability of product, process and marketing innovations
Kaiser et al. (2016)	Danish register data combined with EPO data	1999-2004	Dynamic IV count data models	R&D workers with university working experience as well as recent graduates have economically an statistically large effects on corporate patenting as have R&D workers who join from the corporate world with past university experience

Leten et al. (2014)	Data on 101 Italian provinces and four high-tech industries	1992-1998	OLS fixed effects	Positive link between university graduates as well as scientific publication and technological performance
Cowan and Zinovyeva (2013)	20 Italian regions	1984-2000	IV linear fixed effects	Establishment of new universities led to increase in regional innovation activity
Rothaermel and Ku (2008)	81 global pharmaceuticals	1980-2001	Count data models	“Critical role” of universities as knowledge source
Valero and van Reenen (2016)	Regional data for 78 countries	Back to 11th century	OLS, descriptive	Supply of skilled labor main driver of economic growth and innovation
Gibbons and Johnston (1974)	30 UK innovations	Unclear	Descriptive	Public research benefits private innovation
Martin and Irvine (1981)	Case study of UK radioastronomy industry	WWII-80s	Descriptive	Innovation primarily driven by university educated scientists
Klevorick et al. (1995)	Yale survey	1984	Descriptive	Training of scientists is main source of public-private knowledge transfer
Nelson and Rosenberg (1994)	Various sources	Long time series	Descriptive	Long-term effects of basic research may underestimate the impact of science on industrial innovation
Lissoni et al. (2009)	Danish EPO patent inventor data	1977-2003	Descriptive	The abolishment of the professor’s privilege in Denmark (the Danish Bayh-Dole act) led to a surge in university patenting
New firm creation				
Saxenian (1996)	Silicon valley and Boston case studies		Descriptive	Strong relationship between presence of top research institutions and regional agglomeration of university startups
Bania et al. (1993)	Six US manufacturing industries	1976-1978	Descriptive	More startup activity around universities but no more successful than other startups
Massey et al. (1992)	US science parks	1976-1978	Descriptive	Science park startups have comparatively lower growth rates
Storey and Tether (1998)	Review of European literature	n/a	n/a	University spinoffs have lower growth rates than other startups
Zhang (2009)	4670 US venture capital backed firms	1992-2001	Descriptive, OLS	No difference between university startups and other startups in terms of many key performance variables
Baptista and Mendonça (2010)	Portugese register data	1992-2003	Count data entry models	Proximity to university positively affects the number of startups

Fritsch and Aamoucke (2013)	German CIS data	1995-2008	Count data entry models	Proximity to university positively affects the number of startups
DiGregorio and Shane (2003)	Data on 101 universities and 530 startups	1994-1998	Count data entry models	Faculty quality and university equity investments key drivers of spinoff performance
International scientist mobility				
Docquier and Rapoport (2012)	Literature review	n/a	n/a	High-skilled migration to date is most important type of mobility
Freeman (2013)	Various sources	n/a	Descriptive	High-skilled migration key to knowledge flows and trade between countries
Nathan (2014)	Literature review	n/a	n/a	Strong positive effects of skilled migration on innovation, productivity, trade and entrepreneurship
Franzoni et al. (2014)	GlobSci data	2001	Binary choice IV models	Migrant scientists outperform domestic scientists
Franzoni et al. (2014)	GlobSci data	2001	Binary choice IV models	Return migrant scientists do as well as scientists who never migrated
Franzoni et al. (2012)	GlobSci data	2001	Binary choice models	Career opportunities make scientists leave, family reasons make them return
Stuen et al. (2012)	2300 US science and engineering departments	1973-1998	OLS IV	Migrant students are at least as well performing as domestic ones in terms of scientific output
Stephan and Levin (2001)	250 most cited papers in US Academy of Sciences & Engineering	1980-1990	Descriptive	Migrant scientists disproportionately often among star scientists
Gaulé and Piacentini (2013)	16000 graduates from 16 US chemistry departments	Unclear	Count data model	Chinese graduates outperform domestic graduates in terms of published papers
Gibson and McKenzie (2014)	Survey data for islands in the Pacific Ocean	1993-2007	Propensity score matching	Migrant scientists are more productive and receive more citations
Hunt and Gauthier-Loiselle (2010)	US state-level data	1950-2000	IV Count data models	Increase in migrant students leads to an increase in state-level patenting
Hunt (2011)	US National Survey of College Graduates	2003	Count data models	Migrant students have higher propensity to patent and to start new firm

Wadhwa et al. (2008)	Large number of startup founders and CEOs; US survey data	1995-2005	Descriptive	Tertiary educated migrant students have higher propensity to start new firm
Kerr and Lincoln (2010); Kerr et al. (2013)	Breakthrough patent and immigration data; city-level data; 362 observations	1975-1984	Linear fixed effects	Immigrants do at least as well as domestic scientists in terms of patent quality
Chellaraj et al. (2008)	US regional-level datasets	1963-2001	OLS	More foreign-born graduate students are associated with more university and corporate patenting
Kerr (2008)	NBER patent data	1985-1997	Linear fixed effects	Migrants accelerate knowledge flows
Gagliardi (2014)	British CIS data matched with register data	2004 and 2007	IV OLS	Foreign born scientists have statistically significant effect on corporate innovation
Bosetti et al. (2015)	Panel of 20 European countries	1995-2008	IV OLS	More migrant scientists lead to more patenting and more patent citations
Ozgen et al. (2013)	Dutch CIS and register data	2002	IV probit	Immigrants are less innovative compared to domestic workers
Song et al. (2003)	Case studies and patent citations data; 28 mobile engineers	1975-1995	Descriptive	The propensity of a Korean firm with a return migrant from the US to cite a US patent is larger than for a Korean firm without such a return migrant

5.2 HOW IMPORTANT IS THE MOBILITY OF R&D PERSONNEL FOR INVESTMENT IN R&D AND KNOWLEDGE DIFFUSION?

The best way to send information is to wrap it up in a person.

– J. Robert Oppenheimer
(quoted in Stephan, 2006: 71)

Section 5.1 has pointed out that there exist important relationships between university and industry. This subchapter deals with one of the most prominent mechanisms through which such spillovers come about: the mobility of R&D workers.

The importance of “job hopping scientists and engineers” (Agarwal et al., 2009, p. 1349) has been highlighted by Arrow (1962). He stated that “mobility of personnel among firms provides a way of spreading information” (1962, p. 615), and this claim has been verified by many subsequent papers of which this subchapter provides a review.

Localization of spillovers

The more recent literature departs from the observation that knowledge spillovers are geographically localized. The seminal work in that literature is a study by Caballero and Jaffe (1993b) that showed a strong correlation between the location of innovating firms and their probability to cite one another. They used two cohorts of US patent applications that contained 950 patents that received 4750 citations and 1450 patents that received 5200 citations. These cited patents were compared to patents from other geographic areas that are otherwise similar to the focal patents with respect to application date and technology class. Their probit estimation results include, depending on the level of analysis (state/county), between 256 and 4217 observations and show that patents are more likely to be cited in patents assigned to geographically closer firms than by more geographically distant firms; this effect is stronger the smaller the broader geographic area. In a

robustness check of Caballero and Jaffe’s (1993) study, Thompson and Fox-Kean (2005) show that the original results were upward biased by the selection of control group patents and the respective level of aggregation of technology classes.

The results by Caballero and Jaffe (1993) not only triggered a large amount of literature on the localization of spillovers ((Audretsch and Stephan, 1996; Breschi and Lissoni, 2009; Cockburn and Henderson, 1998; Hall et al., 2005; Klepper and Sleeper, 2005; Rosenkopf and Almeida, 2003; Saxenian, 1994; Stephan, 1996) but also led scholars to ask what actually causes this localization. Almeida and Kogut (1999) use the methodology suggested by Jaffe et al. (1993) to show that there indeed is a strong correlation between the mobility of inventors employed in US semiconductor firms and the localization of knowledge, but that localization of knowledge exists in a few geographic regions, most importantly Silicon Valley and, to a smaller extent, the New York-New Jersey and Pennsylvania areas only. In a later paper, Rosenkopf and Almeida (2003) ask how the localization of knowledge can be overcome. They measure knowledge flows by US semiconductor patent citation data that include data on 68 firms, 4562 citations between 1200 citation dyads and 992 patents observed between 1990 and 1995, and they try to assess how labor mobility (as well as the formation of research alliances) can help to overcome a local search. They find that labor mobility is positively correlated with knowledge flows between firms, and this result is true independent of geographic distance and increases the more distant firms are in technology space. Almeida and Kogut (1999) use a set of “major” – that is, the 25 percent most cited – US semiconductor patents to provide evidence that knowledge indeed is localized and that labor mobility enhances the transfer of knowledge across firms. Stolpe’s (2002) study also shows a positive link between labor mobility and an increase in subsequent mutual patent citations by applying Jaffe et al.’s (1993) methodology. He uses US patents in the LCD industry filed between 1976 and 1995.

Song et al. (2003) add an international perspective to the link between labor mobility and knowledge flows as measured by patent citations. They study the boundary conditions under which knowledge spillovers are likely to be more imminent by using US semiconductor patent citation data for the period 1980-1999 and distinguish between mobility events of engineers who move to a US rather than a non-US firm. Their data set comprises 180 mobile engineers and 86 cross-border moves, leading to 534 observations. Dynamic count data regressions show that citations from the hiring firm to the firm an engineer was hired from are more likely to occur if the patenting activity of the hiring firm is less dependent on its past patenting activity and if, similar to Rosenkopf and Almeida (2003), the engineer joining the new firm has expertise in more distant technology fields as well as if the new worker possesses expertise in fields that are not key to her new employer.

Similarly, Tzabbar (2009) studies the link between the hiring of workers and the technological positioning of the hiring employer in the US biotechnology industry. He estimates hazard rate models for the probability of technological repositioning conditional on recruitment events and a large set of control variables using a combination of data on US biotechnology firms with the NBER patent data base (Hall et al., 2001). The estimation results based on 2643 hiring events observed between 1973 and 1999 show that there indeed is a strong link between the technological repositioning of a recruiting firm and the hiring of scientists from other firms who have a technologically distant patenting record. To account for endogeneity of the hiring decision, he applies a Heckman selection model for “distant” hirings. His selection model seems to lack, however, exclusion restrictions and to be identified by functional form only.

That geographic proximity still matters to date has been shown in a more recent study by Belenzon and Schankerman (2012), who investigate the link between geographic proximity and patent citations to university

patents and scientific publications. They use data on 184 research universities in the US and trace their (forward) patent citations for the time span 1975-2006 and estimate OLS models for the probability that a private sector firm cites a university patent. In line with prior research, they show that university patents are less likely to be cited for further away firms; this effect is less strong for scientific publications. There also is substantial variation in citation probabilities across state borders with fewer citations to university patents in states with lower quality universities. To check if endogeneity problems might possibly affect their results, they use a natural experiment from Michigan, where non-compete clauses were inadvertently introduced in 1985, which should slow the diffusion of knowledge; this prediction is indeed found in the data.

Incoming mobility and innovation

While technological repositioning and citation flows clearly constitute important innovation outcome variables, the effect of mobility on patent count constitutes an even more direct measure of innovative production. To assess the link between scientist mobility and patent counts, Hoisl (2007) uses data from a survey of European inventors combined with EPO data to show that inventor mobility is positively associated with an individuals’ inventiveness. She uses an instrumental-variables approach to control for the potential endogeneity of mobility and uses the patent data to trace inventors and their employment history.

A key problem with the use of patent data to track the mobility of inventors is, however, that mobility events go unnoticed if the inventor does not subsequently take out an additional patent: if an inventor does not appear in the patent data after her last patent, that might be because she stayed with her employer and stopped patenting or because she left the employer and subsequently stopped patenting. Either way, mobility events may go unnoticed if an inventor only has one patent. Studies that track the mobility of inventors by patent data are hence based on inventors that keep patenting.

They hence ignore (im-)mobility events that did not lead to additional patents and may confuse immobility with becoming patent-unproductive, which is an issue that might heavily bias the interpretation of existing studies but that did not receive much attention in the existing literature.

The paper by Kaiser et al. (2015) overcomes the problem of potentially wrongly assigning (im-) mobility events to inventors by using linked employer-employee register data combined with patent data for Denmark and the time period 1990-1995. Kaiser et al. (2015) study both incoming mobility (a focal firm hires an R&D worker from another firm) and outgoing mobility (a focal firm loses an R&D worker to another firm). The paper finds economically and statistically significant evidence for mobility to increase patent counts of the hiring firms compared to immobile R&D workers. Importantly, the effect of incoming R&D workers is stronger if the incoming worker was hired away from a patenting firm. Moreover, the study also finds a positive link between workers leaving the focal firm for another firm that is patent-active, while there is no such effect for workers leaving to non-patenting firms. The paper uses dynamic count data models that instrument mobility by labor supply-side factors and that account for firm fixed effects. They additionally substantiate their empirical evidence by using propensity score matching.

In a follow-up paper, Kaiser et al. (2016) study the effect of R&D workers who leave universities and join the corporate world. Using similar data and estimation methods, they find that incoming university joiners have a substantial positive effect on their employers patenting activity.

The focus of the literature reviewed in this subchapter so far has been on the mapping between labor mobility and patenting activity as well citation patterns. Kim and Marschke (2005) take a more “defensive” position by arguing that it is not necessarily the inflow of new knowledge that leads hiring firms to patent more

but that firms in industries characterized by high labor turnover patent more inventions to forearm themselves against involuntary knowledge spillovers due to the loss of workers to competitors. They derive a game theoretical model and show that the risk of employee departure reduces both R&D expenditures and increases the propensity to patent. This key prediction is reflected by the count data models they estimate on the NBER patent data combined with CPS data on regional-level labor mobility of scientists and engineers. The data consist of 21,030 firm-years and 2740 unique firms and trace the period 1975-1992. Their main empirical approach is a random effects Poisson model. They do, however, recognize the importance of state dependence, firm-specific time-invariant effects as well as the potential endogeneity of mobility by applying a dynamic count data model that accounts for endogenous variables. The key results are that higher labor mobility corresponds to a higher ratio of patents to R&D: halving industry-specific mobility rates would lead to a reduction mean patent-to-R&D ratios by two percent.

In their study on German manufacturing firms, Müller and Peters (2010) study labor “churning”, the replacement of one worker by another, thereby separating the effect of replacement from the net change in R&D workforce. Using data from the German CIS on 1,576 firms recorded in 2005, 2006 and 2008, they estimate simultaneous probit models for product and process innovation and instrument churning by its lagged values. They find there is an optimal amount of churning where the associated cost, i.e., training cost, equate the returns from churning, i.e., better employer-employee matches.

Mobility of university scientists and innovation

Except for Kaiser et al. (2016), the literature reviewed so far is only concerned with mobility to and from private sector firms. A few additional papers deal with mobility from universities to study how university hirings affect knowledge flows and citation patterns.

Early work by Anselin et al. (1997) has its roots in the literature on the geographical localization of spillovers. They assume that both knowledge spillovers from universities and the development of human capital by universities attract corporate R&D. They use data on 4200 new product announcements in 1982 and estimate knowledge production functions by OLS and spatial models for the number of innovations in the high technology sector aggregated to 125 MSA levels matched with regional employment data from the US Small Business Administration. The study not only provides strong evidence for localized spillovers but importantly differentiates between corporate R&D and university research. It finds statistically and economically significant evidence for local spatial knowledge spillovers between university research and innovative activities in the high-tech sector.

While the Anselin et al. (1997) study is at the regional level, Herrera et al. (2010) use firm-level data to analyze the effects of inward mobility from universities to corporate R&D. They use data on 35 Spanish manufacturing firms that they match to the same number of control group firms to mitigate endogeneity caused by the non-randomness of moves from university to industry. Their data spans the time period 1999- 2001, and they find that both external and internal R&D are contemporaneously positively associated with mobility from university, while positive effects on patenting occur only one year after the move.

Herstad et al. (2015) use a much more comprehensive matched-employer-employee data set comprising of 3197 observations on Norwegian manufacturing firms traced between 2001 and 2006. This data is linked to the Norwegian CIS. They find that university hires are positively linked to firm-level inventions but not to innovation (a distinction that is possible in the CIS data), while the latter is positively affected by hirings from firms from related industries. University scientists are hence important drivers of inventiveness, but their presence does not suffice to generate innovations, i.e., commercialized inventions.

Outgoing mobility and innovation

The literature on labor mobility and innovation started by studying the effects of incoming labor on innovation outcomes and citation patterns. Meanwhile, a few studies look at the impact of outgoing labor, i.e., the loss of an own worker to another firm. While it seems intuitive that outward mobility would harm the former employers due to involuntary knowledge spillovers to rival firms, as pointed out by Kim and Marschke (2005), the literature has by and large come to the opposite conclusion: outward mobility may increase both knowledge flows as measured by citation patterns and innovative activity of the firm losing a worker. The key explanation here is that the former worker stays in touch with her former colleagues and that the associated exchange of information is more valuable for stronger knowledge bases of the new employer. However, the effect of incoming mobility is stronger than that of outward mobility. In that vein, the Kaiser et al. (2015) paper for Denmark discussed above finds that outward mobility does have positive effects on patenting activity of the firm that loses workers if they go to a patent-active firm.

Nakajima et al. (2010) use the NBER patent data to estimate patent production regressions to find evidence for an interesting prediction they derive from a simple game theory model: patent productivity effects from mobile inventors (“networked” inventors in the language of Nakajima et al.) are mostly driven by a better inventor-employer match caused by job transitions.

Storz et al. (2015) add a cross-country perspective to the discussion of the effects of labor mobility on innovation. They conduct a case study in the video game industry, where they compare the productivity of game-developing teams in Japan and the US conditional on labor mobility. They show that labor mobility enhances productivity in the US, while it has a negative impact for Japanese firms; they attribute this effect to cultural differences between the two countries. However, mobility within firms that is associated with changes in the job function has a positive effect in both countries.

While Kaiser et al. (2015) as well as Nakajima et al. (2010) use patent counts, Correidoira and Rosenkopf (2010) use patent citations as their outcome variable of interest. They estimate zero inflation negative binomial count data models on around 150 semiconductor firms observed in two different time periods (1980-1989 and 1990-1995), leading to roughly 42,000 patents and 140,614 observations. They find that not only inward but also outward mobility is associated with an increase in the number of patent citations to the firm the former employee joined. Interestingly, the effects of outward mobility are stronger if the firms that exchange workers are geographically distant.

Patent citations are also in the focus of Agrawal et al. (2006). They find that mutual patent citations are more likely to occur if one worker left the focal firm for another employer; this effect proves to be more important than management strategy effects. Their study is based on the NBER patent data base as well and includes around 400,000 citing patents across all US industries in the full sample. They seek to identify causal effects by comparing similar patents of firms that encountered labor mobility and those that did not.

Hence, labor mobility is generally associated with positive effects on firms' innovativeness and with knowledge diffusion. That these positive effects are not restricted to innovation and knowledge diffusion only is highlighted by a set of studies that analyze the mapping between mobility and productivity or other firm performance measures. In that respect, Maliranta et al. (2009) show that hiring R&D workers to a firm's non-R&D activities increases productivity and profits using matched employer-employee data for Finland. Using the Kaiser et al. (2015) data for Denmark, Parrotta and Pozzoli (2012) estimate structural production functions to show that labor mobility leads to economically and statistically sizeable positive productivity effects. Stoyanov and Zubanov (2014) also use Danish register data to estimate the effects of knowledge spillovers generated through worker mobility and find that most

of the gains from spillovers is absorbed by the employer profits. Finally, Tambe and Hitt (2013) find positive productivity effects of mobile ICT workers.

Determinants of labor mobility

Existing studies have primarily been concerned with the consequences of mobility for firms and knowledge diffusion. Mobility is, however, an inherently personal event, which leads Palomeras and Melero (2010) to study why labor mobility of inventors occurs in the first place. Tracking inventors that are assigned to IBM patents in the NBER patent data, 1264 inventors and 6788 patents, they find that the main determinants of a move are the quality of the inventor's work and complementarities of an inventor's knowledge and the knowledge of other inventors at the new employer are prime drivers of mobility. However, a mobile worker's match with the technological competence of her new employer only plays a subordinate role.

Moves to and from technology-driven firms, of course, may also have consequences on the wage rate of the mobile worker. Møen (2005) uses Norwegian-matched employer-employee data to study the wage trajectories of scientists who start their careers in R&D intensive firms. He shows that their wage profile is initially low but overtakes that of workers who did not start in an R&D intensive firm later on. Balsvik (2010) also uses Norwegian register data to study productivity effects of mobile employees with employment experience in a multinational firm, showing that they are more productive than comparable workers without such experience. Wage effects are also in the focus of the Finnish study Toivanen and Väänänen (2016), who study wage premiums for inventors. They find one-off wage effects of three percent and long-term effects of highly cited patents of 30 percent.

Labor mobility may obviously be driven by legal aspects. Non-compete agreements (NCAs) and a firms' propensity to enforce patents before court may restrict the movement of labor. NCA alter the supply of mobile

labor by construction, while a firms' litigiousness may decrease the demand for mobile labor. At the same time, our review of the literature on mobility and innovation has shown that mobility generally is beneficial to innovation. This implies that legislation that restricts mobility may impede innovation, which is a relationship that Mansfield (1995) discussed. Marx et al. (2009), who use the exogenous shock of the inadvertent Michigan NCA enforcement law to identify causal effects, show that NCAs indeed substantially reduce labor mobility; this result is shared by Fallick et al. (2006). Belenzon and Schankerman (2012) as well as Marx et al. (2015) demonstrate that NCAs are not only bad for mobility but that they have negative effects on the diffusion of knowledge as well. By the same token, NCAs, however, also restrict the leakage of knowledge to competitors and hence stimulate innovative activity, which is why NCAs are enacted in the first place. Cooper (2001) derives a game-theory model that describes the tension between the two counterbalancing effects of NCAs.

The litigiousness of firms and its effect on knowledge diffusion are explored by Agarwal et al. (2009) as well as Gambardella et al. (2014). Agarwal et al. (2009) find evidence for a negative effect of a firms' reputation to enforce patents on both citations and mobility for 137 US semiconductor firms. They use a dynamic panel data model and fixed effects. They also attempt to control the potential endogeneity of labor mobility by lagged values of the mobility variables. In a related paper, Gambardella et al. (2014) show that reputation for litigiousness not only reduces labor mobility but that it reduces the mobility of particularly valuable scientists more than that of less productive ones. Finally, Samila and Sorenson (2011) suggest that NCAs may not only impede innovation but innovative activity by scientists as well.

Wrap-up

Our review of the literature on innovation and mobility clearly shows that there is a positive relationship between the mobility of labor and innovative activity, measured by patent counts, as well as knowledge diffusion, measured by patent citations. Mobility does not even appear to be a double-edged sword, since existing studies show that both patenting and knowledge absorption of the firm that loses a worker can increase due to the departure of R&D workers. Consequently, policies that restrict labor mobility (e.g., NCAs) have a negative effect on innovative activity and knowledge diffusion. Recent research has either tracked mobile inventors by using patent application data, which implies that mobility is only observed if a previous inventor applies for additional patents or is used as register data, which allows the exact tracking of a scientist's labor market history but that does not allow for studying individual inventors. The use of register data and identification of inventors in this data as well as the design of an appropriate empirical identification strategy would hence constitute important next steps in our understanding of the mapping between labor mobility and innovation. A first step in this direction has already been undertaken by the World Intellectual Property Organization by establishing a database that allows tracing inventors across time and geography. Miguélez and Fink (2013) present the first descriptive evidence.

TABLE 8.*Results overview*

Study	Data	Period	Method	Main finding
Localization of spillovers				
Jaffe et al. (1993)	950 patents with 4750 citations; 1450 patents and 5200 citations	1975 and 1980	Binary choice models	Citation more likely the more geographically closer firms are
Almeida and Kogut (1999)	NBER patent data; US semiconductors; 131 and 172 major patents	1980 and 1985	Descriptive statistics with control patents	Localization primarily exists in Silicon valley and New York, New Jersey and Pennsylvania areas
Rosenkopf and Almeida (2003)	US semiconductor patents, 68 firms, 4562 citation	1980-1989	Descriptive statistics with control patents	Localization primarily exists in Silicon valley and New York, New Jersey and Pennsylvania areas
Stolpe (2002)	1398 US patents in the LCD industry by 2116 inventors	1976-1995	As in Jaffe et al. (1993)	Positive link between labor mobility and patent citations
Song et al. (2003)	US semiconductor patents; 189 mobile engineers, 534 observations	1980-1999	Dynamic count data regressions	Positive link between labor mobility and patent citations, but more likely if hiring firm is less dependent on past patenting and if mobile scientists are from a technologically more distant field
Tzabbar (2009)	US biotechnology; NBER data, 2643 hiring events	1973-1999	Hazard rate models; Heckman selection model for hiring decision	Strong link between hiring patterns and technological repositioning
Belenzon and Schankerman (2013)	184 US research universities and their patent citation patterns	1975-2006	OLS	University patents less likely to be cited by geographically more distant firms; state borders matter
Incoming mobility and innovation				
Hoisl (2007)	PatVal survey of European inventor data	1977-2002	IV for mobility	Mobile inventors are more patent active than immobile ones

Kaiser et al. (2016)	Danish register data	1990-1995	Dynamic IV and fixed effects count data models	Mobile inventors with previous exposure to university research are economically and statistically significantly more patent productive than workers without such previous exposure
Kaiser et al. (2014)	Danish register data	1990-1995	Dynamic IV and fixed effects count data models	Mobile inventors and in particular those from patenting firms are economically and statistically significantly more patent productive than immobile workers or workers without experience in patenting firms
Kim and Marschke (2005)	NBER patent data combined with MSA-level data from CPS data; 21030 firm-year observations, 2740 firms	1975-1992	Dynamic IV and fixed effects count data models	Mobile inventors with previous exposure to university research are economically and statistically significantly more patent productive than workers without such previous exposure
Müller and Peters (2010)	German CIS data; 1576 firms	2005, 2006, 2008	Simultaneous IV probit models	There exists an optimal amount of labor churning where the benefits to worker replacement balance out the associated cost
Anselin et al. (1997)	Data on 4200 new product announcements combined with MSA-level regional data	1982	Spatial models, OLS knowledge production functions	Strong evidence for localized spillovers in particular for university research and high tech firms
Herrera et al. (2010)	35 Spanish manufacturing firms	1999-2001	Propensity score matching	External and internal R&D is positively correlated with mobility from university; positive mobility effects on corporate patenting a Occur with a one year lag
Herstad et al. (2015)	Norwegian register data and CIS data; 3197 observations	2001-2006	Probit	Positive effects of university hirings on corporate inventiveness but not innovation

Outgoing mobility and innovation

Nakajima et al. (2010)	NBER patent data; 33178 observations	1963-1999	Count data models	Positive patent productive effects of workers who left a firm; effect is caused by better inventor-employer matches caused by transition
Storz et al. (2015)	US and Japanese video game industry	1999-2009	OLS	Labor mobility increases innovation in the US while it has a negative effect in Japan
Correidoira and Rosenkopf (2010)	150 US semiconductor firms in two time periods; 42000 patents and 140614 observations	1980-1989 and 1990-1995	Negative binomial count models	Outward mobility associated with increase in citations to the firm the newly hired worker came from

Agrawal et al. (2006)	NBER patent data; 400000 citing patents across all US industry	1990	Descriptive; “comparable” patents with and without mobility	Increase in mutual citations if mobility events occur
Determinants of labor mobility				
Palomeras and Melero (2010)	NBER patent data; patents assigned to IBM; 1264 inventors, 6788 patents	1970-1999	Probit random effects	Most important determinants are complementarity between the workers and the new employers expertise as well as the quality of other inventors
Moen (2005)	Norwegian register data; 30000 workers, 750 plants	1986-1995	OLS	Workers in high-tech firms initially have lower wage profile than workers in other firms but eventually overtake them
Toivanen and Väänänen (2012)	Finnish register data; 3253 workers	1998-2006	OLS	Evidence for substantial wage premia for inventors
Marx et al. (2009)	Michigan NCA experiment; 98468 workers	1975-2006	Logit	NCA reduce labor mobility
Fallick et al. (2006, 2010)	Michigan NCA experiment; 44202 workers	1994-2001	Probit	NCA reduce labor mobility
Agarwal et al. (2009)	137 US semiconductor firms	1973-2003	Dynamic IV panel data with fixed effects	A firms’ reputation to litigate patent infringers reduces labor mobility
Ganco et al. (2014)	129 US semiconductor firms	1973-2001	IV OLS	A firms’ reputation to litigate patent infringers not only reduces labor mobility but in particular the mobility of particularly productive workers
Samila and Sorenson (2011)	328 MSAs	1993-2002	Linear fixed effects	NCA impede both mobility and inventiveness

6. What is the effect of knowledge transfer on firm performance or growth?

1. Introduction
 2. Methodology
 3. The effects of private R&D on firm performance and economic growth
 4. Public funding of R&D investment
 5. Public research, education and R&D labor market
 6. **What is the effect of knowledge transfer on firm performance or growth?**
 7. Conclusion
- Literature

In capitalist economies, technology has two faces—a private and proprietary one, and a public and cooperative one. These at once complement each other, and are at odds.

– Richard R. Nelson

Economic argument

As we previously have pointed out in chapters 3 and 4, knowledge and technology are important characteristics of innovation and constitute important drivers for economic growth. In this chapter, we focus on how technological knowledge created at universities can stimulate private sector R&D and contribute to industrial innovation. From a policy point of view, there are complementarities between university research and private R&D. In addition to public support mechanisms such as subsidies and tax incentives which are designed to increase input additionalities (e.g. R&D investments) in the private sector, additional policy mechanisms support the commercialization and transfer of technological knowledge from universities and other research institutes. Combined, these public support policies address the market failure in R&D and innovation and contribute to increased innovation in the private sector, which was discussed in chapter 3.

Chapter 5 focused on how university research can create positive externalities in the private sector through spillover effects as well as labor mobility. These transfer mechanisms deem knowledge created at universities to substantially increase technological opportunities in the private sector. In addition to our findings and reflections in Chapter 5, this chapter deals with how university research can generate industrial innovation in the private sector. We in particular provide insights on how public support mechanisms and university-industry relationships can enhance the diffusion of knowledge and technology, which in turn stimulates industrial innovation. Specifically, we consider academic spin-offs, technology transfer offices, academic consulting and further university-industry as well as entrepreneurial activities.

By establishing such university-industry linkages, universities take an open innovation perspective as described by Perkmann and Walsh (2007). They distinguish between seven specific university-industry links: (i) research partnerships, (ii) research services, (iii) academic entrepreneurship, (iv) human resource transfer, (v) informal interaction, (vi) commercialization of property rights and (vii) scientific publications. The present chapter focuses on research partnerships, research services, academic entrepreneurship and commercialization of property rights. Chapter 3 dealt with the transfer of human resources and the importance of scientific publications for industrial innovation.

A broadly accepted understanding and in-depth comprehensive empirical evidence about the effects of these transfer mechanisms is missing to date. In addition, a comprehensive review of the empirical literature in this field has not been provided. One exception is the study by Perkmann and Walsh (2007), which aims at defining a future research agenda on university-industry relationships. Reviewing the existing literature, they report that university-industry relationships are very common and that the use of the various links varies across industries and scientific disciplines. Empirical evidence about the effects of university-industry relationships is scarce. In a study using a sample of Belgian innovating firms from 2003-2006, Belderbos et al. use CIS data to investigate the impact of international and domestic technology transfer on firms' productivity performance. They analyse a set of transfer mechanisms consisting of R&D contracting, purchase of licenses and other know-how and hiring of specialized labor as well as various knowledge and technology channels. They estimate a dynamic productivity model and find that firms using international knowledge transfer strategies statistically and economically significantly outperform other firms in terms of productivity growth. Interestingly, they find that firms that are engaged in both domestic and international transfer strategies harvest the largest productivity increase. This strong positive effect of diverse knowledge sourcing is in line with Laursen

and Salter (2006), who also account for a diverse set of external knowledge sources.

According to Perkmann and Walsh (2007), which presents US-only evidence, university and industrial research has become increasingly intertwined. They relate this interdependence to factors such as a growing number of governmental initiatives to promote public-private research partnerships and a steadily increasing political pressure on universities to contribute to national economic competitiveness. Several indicators underline this trend: Universities have an increasing propensity to patent (Nelson, 2001), generate increasingly higher revenues from licensing (Thursby et al., 2001) and an increasing number of university scholars are active in academic entrepreneurship (Shane, 2005). Furthermore, universities generate a higher share of their income from industry funding (Hall, 2004) and establish an increasing number of technology transfer offices, industry collaboration support offices and science parks (Siegel et al., 2003).

Research partnerships

Perkmann and Walsh (2007, p. 268) follow Hall et al.'s (2003) approach and define research partnerships as formal collaborative arrangements among organizations with the objective to co-operate on research and development activities. In the context of university-industry collaborations, most of these research partnerships receive public support. Chapter 4 of our report has dealt with those types of university-industry collaborations and showed that the results are mixed with respect to subsidized collaboration. In this chapter, we focus on aspects which have not been considered in the context of subsidized collaboration.

In their seminal paper on industry-science links that is based in Belgian CIS data, Veugelers and Cassiman (2005) report that large firms and firms in the chemical and pharmaceutical industry are more likely to engage in industry-science partnerships. They additionally find that collaboration between science and industry

are undertaken whenever risk does not constitute an important obstacle and when the partners have the objective to share costs. Consistent with the emerging open science paradigm, the authors do not find empirical evidence for the capacity to appropriate the returns from conducting joint innovation to be important for university-industry collaboration.

Empirical evidence on the impact of university-industry collaboration on industrial innovation is scarce. Beck and Lopes-Bento (2016) study the sequential adoption of collaboration partner types with Swiss CIS firm-level data and find that large firms can in particular improve radical and incremental innovation performance by cooperating with science. By contrast, small firms face more obstacles to benefit from collaboration with science. This is particularly so if they do not collaborate with other partners. The authors hence find that small firms can improve their incremental innovation performance by closing collaborative agreements with science partners. Based on their empirical findings, Beck and Lopes-Bento (2016) derive important policy implications for the design of innovation subsidies schemes regarding the requirement for small firms to collaborate (with science partners). The authors suggest that this requirement to receive public support should be reconsidered, at least for incremental innovation projects.

These findings are in line with earlier research by Robin and Schubert (2013). They evaluate the impact of cooperation with public research institutes on firms' product and process innovation using French and German CIS data from 2004 and 2008. Similarly to the recommendations of Beck and Lopes-Bento (2016), they argue that "public private collaborations in research should not be encouraged at all costs, since they may not sustain all forms of innovation (p.149)." According to their results, they find that while cooperating with public research increases product innovation, this form of collaboration has no effect on process innovation.

Danish evidence is provided by Mark et al. (2014), who study the economic impact of university-industry collaboration on productivity by applying a propensity score matching and a difference-in-difference approach on a data set derived from University of Copenhagen. Their results show a significant and positive impact of formal collaboration with research-intensive universities and subsequent labor productivity.

Arvanitis and Woerter (2015) evaluate factors influencing the exploration and exploitation of knowledge in collaboration with universities. They further evaluate the impact of knowledge exploration versus knowledge exploitation on innovation performance using Swiss CIS firm-level data. They find a positive effect on innovation performance for exploitation-oriented firms but no effect for those firms engaged in both exploitive and explorative activities.

Again exploiting Swiss firm-level data, Arvanitis et al. (2008b) investigate whether specific forms of university-industry knowledge transfer have different impacts on firm innovation performance. They find that research partnerships with science seem to improve radical as well as incremental innovation performance, whereas the strength of the effects are of similar magnitude. The general positive effect of research partnerships on innovation performance and labour productivity is supported by a similar study by Arvanitis et al. (2008a).

Research services: Consulting and technology transfer offices

According to the definition by Perkmann and Walsh (2007), academic consulting constitutes paid services performed by university researchers for external clients. These arrangements are hence more asymmetric in nature compared to research partnerships, as the projects are defined more unilaterally by the client. Empirical evidence on the impact of academic consulting on innovation in industries is almost missing, although it would be of considerable interest, as pointed out by Cohen et al. (2002) and Hall (2004). While the impact of academic

consulting on industrial innovation is not well covered by the existing literature, academic consulting is considered as an important means through which university research outcomes is transferred to industry as shown by Cohen et al. (2002) using the Yale survey data.

One of the very few empirical analyses on this topic is performed by Arvanitis et al. (2008b), who do not find that academic consulting impacts firms' innovation performance positively.

Taking a broader perspective, Perkmann et al. (2011) analyse how universities' research quality affects university-industry relationships using a data set from the UK. They find that the relationship between faculty quality and industry involvement is different across academic disciplines and that it depends on complementarities between industrial and academic work. It also depends on resource requirements. Their results suggest that in technology-oriented disciplines, the research quality of a university department is positively related to industry involvement. While for the medicine and biology disciplines their study reveals a positive relationship of departmental faculty quality, these strong effects do not hold for star scientists. With respect to social sciences, they find some support for a negative relationship between faculty quality and industry involvement. From a policy perspective, their findings suggest that differentiated approaches are necessary to promote university-industry interactions.

The transfer of university-created scientific and technological knowledge into economic value has attained much attention from policy makers. One means of university-industry links are university-based technology transfer offices, which act as a mediating institutions between science and industrial innovation (Debackere and Veugelers, 2005). Comparing the technology transfer mechanisms from a sample of European research universities with a detailed description of the case of K.U. Leuven, Debackere and Veugelers (2005, p. 339) analyse a framework incorporating

“the context, the structure and the processes that universities can use to become active players in the scientific knowledge market, managing and applying academic science, technology and innovation from an exploitation perspective.” This framework consists of decentralized organizational approaches and incentives for the stimulation of an active involvement of research groups in the exploitation of their research findings in combination with specialized central services offering intellectual property management and spin-off support (Debackere and Veugelers, 2005). Their findings suggest that critical success factors to stimulate an “effective” commercialization of the academic science base (Debackere and Veugelers, 2005, p. 321) are (i) an appropriate balance between centralization and decentralization within academia, (ii) the design of appropriate incentive structures for academic research groups and (iii) the implementation of appropriate decision and monitoring processes within the TTO.

Academic entrepreneurship and new firm creation

Perkmann et al. (2011, p. 540) define academic entrepreneurship as the development and commercial exploitation of technologies pursued by academic inventors through a company they (partly) own. In this subsection, we focus on academic spin-offs.

In an exceptional study due to its long-term term character, Vincett (2010) surveyed Canadian firms from 1960-1998 and analysed the economic impact of academic spin-off in two distinct science disciplines. He compares the economic impact of academic spin-offs originating from more applied sciences (non-medical natural sciences and engineering) and more basic science (physics). He estimates the economic impacts of academic spin-offs in the period 1960–1998, and compares the estimated effects to the effects of government funding. The findings demonstrate that the effects of academic spinoffs exceed the effects of government funding by a substantial margin. Comparing the different disciplines, he finds that Physics performs actually

between 30 and 60 % better than more applied fields. Accounting for the Canadian context and the long life-time of the analysis, it is important to acknowledge that the Canadian firm samples are un-balanced primarily due to the influence of foreign acquisitions.

The authors conclude that the spin-off impacts provide substantial incremental contributions to national GDP, and the government’s additional tax income gained by the spin-offs is also higher than they spent for the funding (Vincett, 2010, p. 736). These findings have important policy implications, as the analysis provides a quantitative justification for the public investment, allowing the much more important (but less quantifiable) long-term benefit to be regarded as a ‘free’ bonus (Vincett, 2010, p. 736). Notably, the author also argues that the good performance of physics suggests that more emphasis on basic work or on the basic disciplines could actually strengthen the commercialization of academic research. Some support for the positive economic impact of entrepreneurial university activities, specifically from spin-offs, is also provided by the exploratory study of Guerrero et al. (2015) using UK data for 147 universities from 2005-2007.

It is well documented that there is a strong relationship between the regional agglomeration of university spin-offs and top US research universities like Stanford and MIT (Saxenian, 1994). Salter and Martin (2001) point out, however, that the link between public research institutions and the number of *successful* spin-offs is less clear; this conclusion is shared by Bania et al. (1993), who study startup activities in six US manufacturing sectors at the regional level between 1976 and 1978 and link them to the presence of research universities. Massey et al. (1992) study US science parks to conclude that science-park startups are characterized by comparatively lower growth rates. Storey and Tether (1998) review European studies on university spinoffs and find that they have lower growth rates than traditional firms. This conclusion is shared in a more recent study by Zhang (2008), who uses US venture capital

data to show that university spinoffs tend to survive longer but are not different from other startups with respect to the amount of venture capital raised, employment, profit or the likelihood of having a successful IPO.

Baptista and Mendonça (2009) use Portuguese register panel data for the years 1992-2003 and link the data to the regional supply of students and graduates as well as to their proximity to a regional university. They estimate count-data models for firm entry to show that proximity to universities has a positive effect on startup activity. Fritsch and Aamoucke (2013) demonstrate that such links also exist in Germany. Using a comprehensive data set on startup activity in Germany to which they attach the number of local public research institutions, they stress the importance of localized knowledge for innovative startup activity and in particular the contribution of public research institutions for founding activities.

In an attempt to identify why universities differ with respect to the success of their spinoffs, Di Gregorio and Shane (2003) use data made available by the US Association of University Technology Managers (AUTM) on 101 universities and 530 startups that can be linked to them and trace them over the period 1994-1998. Their count-data regressions single out two key drivers of university startup success, namely, faculty research quality and equity investments provided by the university.

From a policy perspective, using an Italian sample of 404 companies, Fini et al. (2011) show that the marginal effect on universities' spin-off productivity depends on local or regional support mechanisms, including legislative support, regional social capital, regional financial development, the presence of regional business incubator and regional public R&D expenses as well as the level of regional innovation performance. They argue that for the design of effective universities, spin-off mechanisms regional settings should be taken into account. Colombo et al. (2012) analyse the effects of incubation on high-tech start-ups on a large sample of

firms in Italy. A business incubator refers to a company or an organization that supports new and startup companies that mainly originate from universities to develop and sustain by providing services such as management training or office space. Their findings show that incubated high-tech start-ups do not take any advantages from engaging in collaboration compared to their non-incubated control firms.

To date, there is little evidence on startups founded by university graduates and students who leave university after graduation as well as their growth and survival prospects. The Danish ministry for Research and Innovation provides a descriptive analysis of Danish students' propensity to start their own businesses that is based on register data for the period 2001 to 2011. It shows that there is a large increase in student start-ups by 43 percent over the time period, that most of these startups are founded by students with a master's degree, that the growth in the number of startups is triple the growth in graduates, that recent graduates are much more likely to found startups than the rest of the population and that student spinoffs are more productive, generate more workplaces and have higher sales than other startups.

Also using Danish data, Nielsen (2014) studies the performance and industry choice of new venture formation by academic entrepreneurs including faculty and graduate students as an important factor for knowledge spillovers and technology transfer. Explicitly, the focus of the study is on the subsequent performance of these new ventures and is measured by survival and growth as well as the choice of the industry. The study considers technical as well as non-technical university education and accounts for industry experience of the academic entrepreneurs. The findings show that technical academics perform better in high-profit as well as in uncertain industries, while non-technical academics only perform better in high-profit industries. The findings indicate that both types of academics have a higher likelihood to enter uncertain industries. The

authors suggest that the absorptive capacity of technical academics makes these entrepreneurs particularly relevant for the transfer of technological knowledge into new ventures in uncertain and unstable environments.

Commercialization of property rights

Since many spin-offs also commercialize university property rights, this paragraph particularly focuses on this specific topic. Perkmann and Walsh (2007, p. 262) define the commercialization of property rights as the transfer of university-generated IP (such as patents) to firms, for example, via licensing. A relevant study is Roessner et al. (2013), who estimate the economic impact of licensed commercialized inventions originating in university research on the US economy. Their approach combines US licensing data from US universities with national input-output model coefficients. Taking into account different assumptions about royalty fees and product substitutions effects, even the most conservative assumptions suggest that the economic impact on GDP, industry output and employment are economically very substantial.

Entrepreneurship and technology policy

Policy has promoted science, technology and innovation parks (STI) as an important part of their innovation policy. Earlier research has shown that being located in a park supports firms to engage in collaboration but does not necessarily lead up to improved performance. The analysis by Vázquez-Urriago et al. (2016) accounts for selection bias and endogeneity and confirms the previous findings that location in a science and technology park positively affects the likelihood to collaborate and increases the likelihood of intangible benefits of collaboration with the main innovation partner. The authors underline that this might be due to a more diverse relationship, which is also supported by Beck and Schenker-Wicki (2014), who analyse the impact of diversity in collaboration for product innovation performance using a large sample of Swiss firms derived from CIS data.

In an earlier study on the performance of 22 Spanish Science and Technology Parks (STP), Vázquez-Urriago et al. (2014) estimate the average treatment effect for firms located in these STPs. Their analysis shows that firms located in STPs have a strong and positive impact on the probability and amount of product innovation. These results still hold when controlled for the endogeneity of STP location. Díez-Vial and Fernández-Olmos (2014) analyse the relevance of Spanish STPs as locations fostering local knowledge sharing and stimulating innovation. Results of their Tobit models indicate that firms with previous experience in collaboration with universities and research institutions benefit most from being located in an STP. The authors argue that this might be because firms with experience are better able to integrate existing knowledge from the STP, and hence the firms can improve their product innovations. Furthermore, their findings suggest that product innovation is more likely when firms with internal R&D reciprocally share the knowledge.

Another focus of policy makers' attention has been the establishment and promotion of (regional) industrial clusters. However, we have to keep in mind that some clusters also organically originate without public support. Here, we focus on clusters with public R&D support. Only very few empirical studies exist that evaluate the effects of clustering for industrial innovation. The role of local or regional clusters to foster local competitiveness in the private sector is highly controversial in academic research. The difference-in-difference estimation analysis by Falck et al. (2010) evaluates the effectiveness of cluster-oriented policy initiated by the Federal state Bavaria in Germany in 1999. The main policy objective was to stimulate firm innovation and regional competitiveness mainly by the means of collaboration among firms. According to the study, the policy succeeded in increasing the likelihood of firms to become innovators in the target industry by 4.6 to 5.7 percentage points. Interestingly, R&D expenditures in those industries decreased by 19.4 percentage points on average. Additionally, the policy supported firms to

engage in collaboration with public research institutes, and the availability of suitable R&D labor increased (Falck et al., 2010, p. 574).

Positive effects of cluster participation is also found by Maine et al. (2008), who investigate the relationship between clustering and growth performance of new technology firms in the US. Their analysis provides empirical evidence that distance from a cluster is negatively correlated with firm growth. Further, the results indicate that the impact of being located in a cluster is greater for biotech firms. The authors argue that geographical proximity to a cluster within a diverse metropolitan area is related to higher growth performance only firms that are strongly integrated in a “broad, downstream supply chain effects”, which apply according to the study to firms engaged in the information and communication technology.

Yet another empirical study on 229 small firms evaluating the effects of cluster policy on R&D productivity in Japan is conducted by Nishimura and Okamuro (2010). The findings of their study show that participation alone in a cluster does not necessarily affect R&D productivity. They find that collaboration in R&D with a partner in the same cluster region leads to a decrease in quantity and quality of patents. However, firms participating in a cluster have a larger number of patent applications when they collaborate with national universities located in the same cluster. The authors suggest that in order to create positive effects of a cluster initiative, it is important to establish a network of wide-range collaboration within and beyond the cluster.

Policy mix, triple helix and national innovation systems

Academics have introduced the analytical model of the triple helix system to characterize university-industry relationships in the context of regional networks of institutional knowledge flows (Cowan and Zinovyeva, 2013; Etzkowitz and Leydesdorff, 2000; Kim et al., 2012). This triple helix system is supposed to foster regional or

national innovation and entrepreneurship. Aligning to the broad system theory, the triple helix system of innovation is defined as a set of (i) components (the institutional spheres of University, Industry and Government, with a wide array of actors); (ii) relationships between components (collaboration and conflict moderation, collaborative leadership, substitution and networking); and (iii) functions, described as processes taking place in what we label the ‘Knowledge, Innovation and Consensus Spaces’ (Ranga and Etzkowitz, 2013, p. 238).

Empirical evidence on the effects of the components and interrelationships within a triple helix system of innovation are very scarce. One exception is the study by Kim et al. (2012), which analyses the effects of triple helix components and their interrelationship with performance indicators such as firm birth and deaths rates in the US at the state level. The evidence of this study is quite mixed. The analysis shows that industrial R&D expenditures stimulate regional firm birth more than university and government R&D spending. There exist synergy effects between university and government R&D as they indirectly affect firm formation in a region. The authors argue that the synergy between university and industrial R&D leads to a higher sustainability of firms, while other interactions within the triple helix system increase firm death, such as (1) university and government R&D and (2) government and industrial R&D. Other factors such as higher educational standard in a region, lower tax rates, higher quality of life, lower housing prices and better health insurance standards also stimulate firm formation. Further, university R&D can play an important role as an ‘entrepreneurial mediator’ in the triple helix system in regions with high entrepreneurial activity (Kim et al., 2012, p. 154). In a region with low entrepreneurial activity, the triple helix system seems to be less effective in stimulating innovation in the private sector.

Wrap-up

Literature has pointed out that knowledge and technology are important characteristics of innovation and constitute important drivers for economic growth. Our

review also focuses on how technological knowledge created at universities can stimulate private sector R&D and contribute to industrial innovation. In addition to public support mechanisms such as subsidies and tax incentives, which are designed to increase input additionalities such as R&D investments in the private sector, additional policy measures support the commercialization and diffusion of technological knowledge from universities and other research institutes. To review the effects of knowledge and technology transfer from academia to the private sector, we accounted for policy instruments, such as research partnerships, research services including academic consulting, technology transfer offices, academic entrepreneurship (i.e., academic spin-offs), intellectual property rights and further entrepreneurship and technology policies. Taken all together, these public support policies address the market failure in R&D and innovation and aim to contribute to increase innovation in the private sector. Importantly, our review finds that a broad accepted empirical evidence on transfer mechanisms is lacking. Hence, we focused on individual studies that address the specific policy measures indicated above.

First, we find that research partnerships have a positive effect on innovation. However, there exists a great deal of heterogeneity. Second, empirical evidence on academic consulting is missing. Third, there are mainly studies on technology transfer offices that highlight appropriate configurations of TTOs, but there is only very little robust evidence on the outcomes of TTOs. Fourth, reviewing the literature on the outcomes of academic entrepreneurship measures, we found a large amount of heterogeneity in the studies. Nonetheless, one can state that there are more academic spin-offs than “ordinary” start-ups, but they do not necessarily perform “better”. Fifth, there is not much empirical literature on the outcome effects of intellectual property rights. Finally, there exists almost no robust empirical evidence on the effectiveness of appropriate policy mixes. Generally, the literature

emphasizes that university R&D can play an important role as an ‘entrepreneurial mediator’ in a region with high entrepreneurial activity.

7. Conclusion

Even though the literature reviewed in this survey is generally based on weak empirical identification, there are some broad findings that have so far been produced. First, the private returns to R&D appear to be large and larger than the returns to alternative investments. Second, private R&D and R&D subsidies – be it in the form of tax deductions or direct subsidies – are positively correlated, and there is no evidence for crowding-out effects. Third, R&D co-operation increases private R&D. Fourth, there appear to exist complementarities between alternative sources of funding. Fifth, the mobility of R&D workers – and in particular movement of university scientists to industry – is positively related to an increase in corporate innovation. Sixth, there are comparatively many university spinoffs, but these are no more successful than non-university spinoffs. Seventh, scientists with a migration background outperform domestic ones. Eighth, universities constitute important collaboration partners. Ninth, clusters enhance collaboration, patents and productivity.

A problem common to much of the literature reviewed in this survey is that it measures simple correlations. Few studies use quasi-experiments or sensible instrumental variables estimation. It hence appears difficult to arrive at sharp policy conclusions. By the same token, and given the vast amounts of money spent by governments on R&D all over the world, it seems advisable to allocate some of these funds to policy

experiments as is common practice in labor economics. Better data simply leads to better informed and more comprehensive policy advice.

Another problem for economic policy is that little is known about the optimal design of policy measures, since most studies only analyze a single policy measure. This prevents an analysis of how different policy measure should be combined and how large each component should be. Similarly, little is known about the long-run effects of government intervention.

With respect to labor mobility, the presumption that mobility of university scientists to industry enhances corporate innovation ignores that such moves entail a loss to academia that has not yet been quantified.

A final problem is the aggregation of the primarily micro-founded results. The analyses covered in this review are all partial and do not consider second-order effects like changes in the competitive environment due to innovation. It seems, however, to be premature to tackle the aggregation problem as long as the micro-foundations remain weak.

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VÆKST GENNEM VIDEN

DEA er en ideologisk uafhængig tænketank, der arbejder for, at Danmark øger sin værdiskabelse og vækst samt tiltrækker internationale virksomheder gennem viden om uddannelse, forskning og innovation.

Tænketanken DEA kæmper grundlæggende for, at flere unge får en uddannelse, der efterspørges; at forskning bliver omsat til innovation i private og offentlige virksomheder, og at Danmark er et attraktivt land for videnbaserede virksomheder.

DEA vil nå sine mål gennem:

- Analyser og undersøgelser, der styrker DEAs dagsorden
- Involvering af virksomheder, uddannelsesinstitutioner og organisationer via partnerskaber og projekter
- Udfordring af vanetænkning og bidrag til løsning af samfundsudfordringer